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ASSOCIATION D'OCÉANOGRAPHIE PHYSIQUE

Union Géodésique et Géophysique Internationale

PROCÈS-VERBAUX Nº 4

GENERAL ASSEMBLY

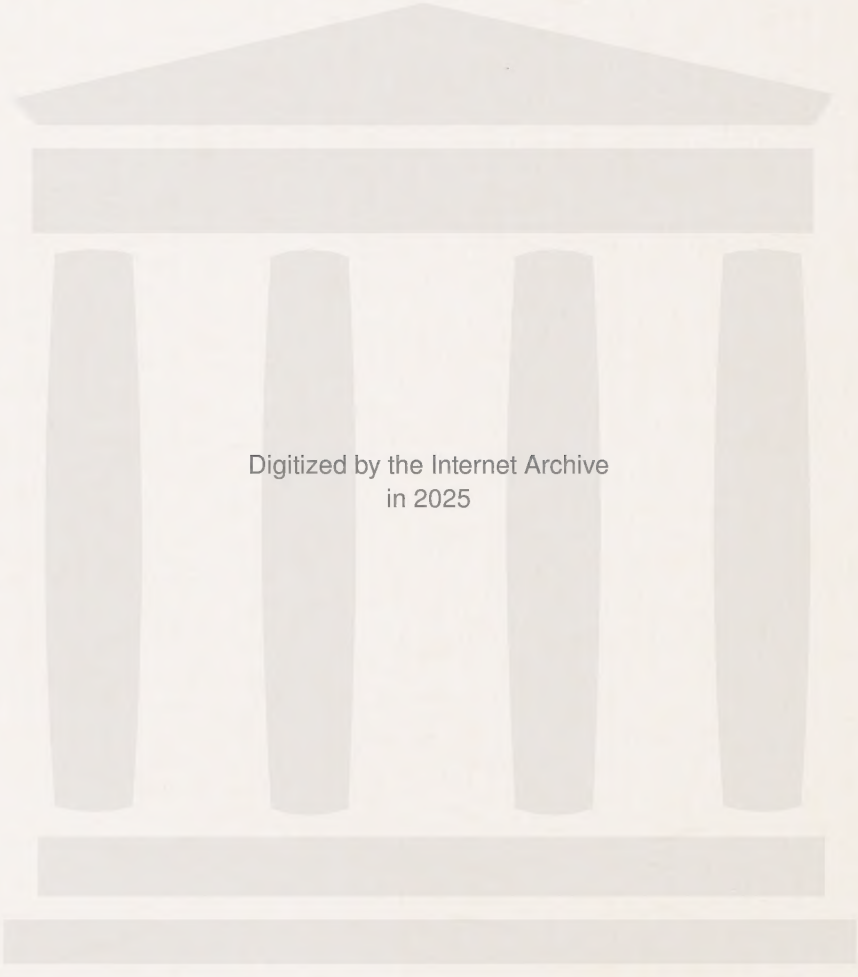
at

OSLO

August 1948

1949

Secrétariat de l'Association: Geofysisk Institutt, Bergen, Norway



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ASSOCIATION D'OCÉANOGRAPHIE PHYSIQUE

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The Association issues two series of publications, viz. "Publications Scientifiques" and "Procès-Verbaux."

The following numbers have already appeared:—

PUBLICATIONS SCIENTIFIQUES.

No. 1. S. F. GRACE:

I. Historical review of dynamical explanations of tides in non-elongated enclosed seas and lakes.

II. Historical review of dynamical explanations of the tides of the Mediterranean, the Baltic Sea, the Gulf of Mexico, and the Arctic Ocean. (1931).

No. 2. Tidal Bibliography (Third instalment). (1932.)

No. 3. Bibliography on tides and certain kindred matters (Fourth instalment). (1936.)

No. 4. PHIL E. CHURCH: Temperatures of the Western North Atlantic from thermograph records. (1937.)

No. 5. Monthly and annual mean heights of sea-level, up to and including the year 1936. (1940.)

No. 6. Bibliography on tides and certain kindred matters (Fifth instalment). (1939.)

No. 7. J. P. JACOBSEN and MARTIN KNUDSEN. Urnormal 1937 or Primary Standard sea-water 1937. (1940.)

No. 8. Report of the committee on the criteria and nomenclature of the major divisions of the ocean bottom. (1940.)

No. 9. B. HELLAND-HANSEN, J. P. JACOBSEN and T. G. THOMPSON: Chemical methods and units. (1948.)

PROCÈS-VERBAUX.

No. 1. Cinquième Assemblée Générale réunie à Lisbonne Septembre 1933. (1934.)

No. 2. General Assembly at Edinburgh, September 1936. (1937.)

No. 3. General Assembly at Washington, September 1939. (1940.)

These publications form a continuation of the "Bulletins de la Section d'Océanographie de l'Union Géodésique et Géophysique Internationale," of which there were 17 numbers, No. 1 being issued in 1921 and No. 17 in 1931.

The General Assembly of the Association was held on the occasion of the Eighth General Assembly of the Union. The meetings of the Association were held in the rooms of the University of Oslo from the 20th to the 27th August 1948

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Officers and Executive Committee
(1946–1948)

President:	Professor H. U. SVERDRUP, Norsk Polarinstitutt, Oslo, Norway.
Secretary:	Professor J. PROUDMAN, The University, Liverpool, 3, England.
Deputy Secretary:	Professor H. MOSBY, Geofysisk Institutt, Bergen, Norway.

Members:

Mr. D. J. MATTHEWS, 10 Kew Gardens Road, Kew, Surrey, England.

Professor T. G. THOMPSON, Oceanographic Laboratories, University of Washington, Seattle, 5, U.S.A.

Professor M. KNUDSEN, Charlottenlund Slot, Charlottenlund, Denmark.

Dr. A. RAMALHO, Estação de Biologia Maŕitima, Cais do Sodré, Lisboa, Portugal.

Mr. P. M. VAN RIEL, Minervalaan 49 huis, Amsterdam, Holland.

Scientific Committees
(1946–1948)

Committee on Tides

Chairman:	H. A. MARMER.
Secretary:	J. PROUDMAN.

Committee on Mean Sea-level and its Variations

Chairman: J. D. NARES.
Secretary: J. PROUDMAN.

Committee on Chemical Methods and Units

Chairman: T. G. THOMPSON.
Members: K. Buch, L. H. N. Cooper, N. W. Rakestraw.

Committee on Criteria and Nomenclature for the Major Divisions of the Ocean-bottom

Chairman: PH. H. KUENEN.
Secretary: J. D. NARES.

Joint Committee of Associations of Physical Oceanography and of Meteorology on Questions of Interaction between the Sea and the Atmosphere

Convener: H. U. SVERDRUP.

Committee on Oceanographical Observations from Atlantic Weather Ships

Chairman: R. H. FLEMING.
Secretary: H. MOSBY.
Members: G. E. R. Deacon, H. Keyser, M. Knudsen.

Committee on Preparation of Technical Handbook in Physical Oceanography

Chairman: H. U. SVERDRUP.
Members: J. N. Carruthers, G. E. R. Deacon, E. C. La Fond, H. Mosby, N. W. Rakestraw.

Delegates and Guests attending General Assembly

ARGENTINA.

Garcia, R.
Monasterio, C. N.
Ruggeri, D.

AUSTRALIA.

Pawsey, J. L.

AUSTRIA.

Defant, A.

BELGIUM.

Tison, L.

CANADA.

Currie, B. W.
Wilson, J. Tuzo.

CHINA.

Koo, C. C.
Tschu, K. K.

DENMARK.

Jensen, H.
Nielsen, N.
Smed, J.

EGYPT.

Kamel, M.

FINLAND.

Jurva, R.
Palmén, E.

FRANCE.

Damiani, L.
Fage, L.
Gougenheim, A.
Heldt, H.
Viaut, A.

GREAT BRITAIN.

D'Albe, E. M. Fournier.
Barber, N. F.
Carruthers, J. N.
Deacon, G. E. R.
Doodson, A. T.
Durst, C. S.
Eady, E. T.
Goldsbrough, G. R.
Johnson, Sir N.
Lumby, J. R.
Mackintosh, N. A.
Marshall, Sheina M.
Normand, Sir C.
Orr, A. P.
Proudman, J.
Sewell, R. B. Seymour.
Sheppard, P. A.
Tait, J. B.
Thorp, J. R.
Wiseman, J. D. H.
Yonge, C. M.

INDIA.

Banerji, S. K.
Gulatee, B. L.
Wadia, D. N.

ISRAEL.

Rosenau, E.

ITALY.

Bossolasco, M.
Viglieri, A.

MEXICO.

Carreño, A. de la O.

MOROCCO.

Debrach, J.

NETHERLANDS.

Boschma, H.
Hauer, A.
Thijsse, J. Th.

NORWAY.

Amble, O.
Bjerknes, V.
Eggvin, J.
Fjeldstad, J. E.
Godske, C. L.
Helland-Hansen, B.
Jakhelln, A.
Kjær, R.
Mosby, H.
Möller, F.
Petterssen, S.
Refsdal, A.
Ruud, J.
Sælen, O. H.
Werenskiold, W.

PHILIPPINES.

Hizon, A. O.

SOUTH AFRICA.

Kent, L. E.

SPAIN.

Menendez, N.

SWEDEN.

Bergeron, T.
Ekman, V. W.

UNITED STATES.

Bundgaard, R. C.
Byers, H. R.
Dietz, R. S.
Fleming, R. H.
Hagen, N. R.
Holmboe, J.
Kaplan, J.
Landsberg, H.
Leifson, G.
Meaney, C. D.
Munk, W. H.
Piggot, C. S.
Revelle, R. R.
Rumbaugh, L. H.
Russell, R. Dana.
Smith, Waldo E.
Spilhaus, A. F.
Stephenson, E. B.
Sverdrup, H. U.

INTERNATIONAL COUNCIL FOR EXPLORATION OF THE SEA.

Blegvad, H.
Russell, F. S.
Thomsen, H.

INTERNATIONAL HYDROGRAPHIC BUREAU.

Nares, J. D.

General Assembly at Oslo August 1948

Agenda

The items numbered by decimals were not circulated four months before the General Assembly.

A. President's Address

The wind and the sea.

B. Administration

1. Report of the Secretary for the period 1939–48.
2. Financial report for the period 1939–47.
3. Financial estimates for the next period.
4. Consideration of draft of new Statutes and By-laws.
5. Election of the President, Vice-Presidents, Secretary, Deputy-Secretary and members of the Executive Committee.

C. Appointment of Scientific Committees

1. Committee on tides.
2. Committee on mean sea-level and its variations.
3. Committee on chemical methods and units.
4. Committee on criteria and nomenclature for the major divisions of the ocean-bottom.
5. Committee on oceanographical observations from Atlantic weather-ships.
6. Committee on preparation of a technical handbook in physical oceanography.
7. Committee to consider a general systematic and abstracting bibliography on physical oceanography and related fields (proposed by Dr. P. Groen, Netherlands).

8. Committee to consider the more general adoption of the universal decimal classification for oceanographical literature and to modernise the present section on physical oceanography of the said classification (proposed by Vice-Admiral J. W. Termijtelen, Netherlands).
9. Joint Committee of Associations of Physical Oceanography and of Meteorology on questions of interaction between the sea and the atmosphere.

D. Reports of Scientific Committees

1. Committee on tides.
2. Committee on mean sea-level and its variations.
3. Committee on chemical methods and units.
4. Committee on criteria and nomenclature for the major divisions of the ocean-bottom.
5. Committee on oceanographical observations from Atlantic weather-ships.
6. Committee on preparation of a technical handbook in physical oceanography.
7. Joint Committee of Associations of Physical Oceanography and of Meteorology on questions of interaction between the sea and the atmosphere.

E. Proposals for Resolutions

1. Regarding tidal observations on the Indian Coast, proposed by Mr. B. L. Gulatee, India:

> "The International Union of Geodesy and Geophysics considers that to provide data for a satisfactory study of mean sea-level and its variations on the Indo-Burma-Malaya-Siamese waters and also for detailed studies of many other geophysical problems, such as the secular subsidence or elevation of land, the present number of active tide-gauge stations on the Indo-Burma Coast is far from adequate, and strongly recommends to the Governments concerned the establishment of a number of additional permanent tide-gauge Observatories on their coasts as soon as practicable."

1.1. Regarding the desirability of a thorough geophysical survey of the Great Barrier Reef of Australia.

F. Discussions

1. Limits of oceans and seas:
   J. D. Nares.
2. Extension of the network of tidal stations of the world:
   J. D. Nares.
3. Growth and decay of waves:
   J. Th. Thijsse.
   G. E. R. Deacon.
4. The applicability of Laplace's differential equations of the tides:
   J. Proudman.

G. Reports

1. J. D. Nares: Report on the work carried out by the International Hydrographic Bureau.
2. J. D. Nares: Report on the preparation of the third edition of the General Bathymetric Chart of the Oceans.
3. Netherlands Meteorological Institute: Activities of the Institute on physical oceanography.

3·1. E. Palmen: Oceanography in Finland.

4. Snellius Expedition: Account of Volumes II and V of the Report on this expedition.

4·1. H. Pettersson: The results of the Swedish Deep Sea Expedition up to 21st June 1948.

5. J. Lamoen: Travaux effectués en Belgique de 1939 à 1948.
6. H. B. Hachey: The present status of oceanography in Canada.

6·1. D. Rochford: Oceanographical work of the Australian Council for Scientific and Industrial Research.

7. B. L. Gulatee: Tidal activities of the Survey of India.
8. N. Menendez: Preliminary oceanographic campaign in the Sea of Alborán.
9. K. Hidaka: Activities in physical oceanography in Japan since 1939.

9·1. E. C. La Fond: Thermal structure of the surface layers of the sea near the Antarctic Convergence.

9·2. R. Serene: Sur les variations de salinité at de temperature de l'eau de mer de surface sur un point du littoral Indochinois.

H. Papers

1. J. Egedal: On the reliability of the derived values of mean sea-level.
1.1. C. D. Meaney: Mean sea-level as a geophysical datum.
2. A. Lundbak: Some peculiar tidal variations.
2.1. H. Lacombe: Étude sur la marée de la Manche centrale.
3. J. N. Carruthers: A new method of continuous current measuring from an unattended buoy.
3·1. O. Dahl and J. E. Fjeldstad: A new current-meter.
3.2. H. Mosby: Experiments on bottom-friction.
4. W. H. Munk: Spectrum of gravity waves at sea.
4·1. N. F. Barber: Recent studies of waves and swell.
5. P. Groen: Internal waves.
6. V. W. Ekman: Turbulent, periodic and mean motions; some measurements in the Atlantic by B. Helland-Hansen and the author.
7. J. Proudman: The theory of mixing of sea-water through turbulence.
8. A. Lundbak: A new accurate burette for small volumes.
8·1. A. F. Spilhaus: Bathythermograph sea-sampler.
9. A. T. Doodson: A study of storm-surges in the North Sea.
9·1. R. S. Dietz: Deep scattering layers in the Pacific and Antarctic Oceans.
9·2. R. Dana Russell: SOFAR: a new oceanographical research tool.

Excursion

An oceanographical excursion left Oslo on 28th August and arrived at Bergen on 31st August, after a journey through Valdres and Sogn. Transport was partly by the research vessels:

Armauer Hansen, *Sjøvern*, *Sjømåleren*, *Herman Friele* (Norwegian).
Explorer (Scottish).

Memoranda on the Agenda

C 7. *Proposal regarding a Bibliography*, by Dr. P. Groen.

Whereas a central, periodically and frequently appearing bibliography, covering all aspects of oceanography and its border fields, and offering a sufficiently detailed classification as well as abstracts of the current literature in the field, would be of much value in oceanographic research, and whereas none of the few existing bibliographies on oceanography, though valuable, possesses all of the above mentioned qualifications,

The "Association Internationale d'Océanographie Physique" resolves to take steps in order to promote the establishment of a periodically appearing, inclusive, classifying and abstracting bibliography on physical oceanography and its border fields, preferably in co-ordination or combination with a bibliography on marine biology, and, if possible, in co-ordination with bibliographies covering other branches of general geophysics; and to appoint a committee to work out detailed plans on the matter.

Explanatory Memorandum

The said bibliography may be either combined with an existing periodical, or edited as an independent periodical by a permanent bureau, which is connected administratively with the "Association Internationale."

It would be advisable that this bibliography should use a sufficiently elaborate classification system, preferably an existing international one, which may, however, have to be further developed for the purpose. With every title there could be given a brief abstract (preferably to be made by the author himself) or else a short indication of the contents. The leaves or sheets should be printed on one side only, so that, by cutting out and mounting on cards, the whole may be worked up directly into a card-index system.

The said committee should be authorised to take up contact with the "Conseil International pour l'Exploration de la Mer," or any other organisation which it finds suitable for the purpose, in order to consider the possibility of combining the bibliography on physical oceanography with one on the biological aspects of oceanography.

C 8. "*Proposal to adopt more generally the Universal Decimal Classification for oceanographical literature and to modernise the present section on Physical Oceanography of the said Classification*," by Vice-Admiral J. W. TERMIJTELEN.

Doubtlessly many students of oceanography will have felt in the last few years the desirability of a well-considered system of classification for oceanographical literature. The rapidly growing number of publications on oceanographical subjects not only asks for a reliable and frequently appearing central bibliography but at the same time for a method of finding them easily and quickly when put away in the libraries of institutions, universities, etc. All larger libraries, of course, possess some form of subject classification, but only if they all use the same system can their catalogues be made easily accessible for outsiders from other institutions, especially if these outsiders come from abroad.

It is well known that many systems of classification exist, but the same motives which led the "Organisation Météorologique International" in 1935 to develop a system, based on the "Universal Decimal Classification," for meteorological purposes make it advisable to adopt the same system for Oceanography. (See "Report of the President to the Conference of Directors at Harrow, September 1935," published by O.M.I., 1937.)

The U.D.C. satisfies the four principal requirements essential for a system of classification. These requirements are:

(*a*) the system must be simple,
(*b*) it must be flexible,
(*c*) it must be internationally recognised and adopted,
(*d*) there must be an institution responsible for keeping the system up to date.

At first sight the simplicity of the U.D.C. may be questioned and the numbers for the minor subdivisions may be considered long, but practical experience has shown that this apparent disadvantage is of no essential consequence.

The flexibility is obvious, because by adding figures behind the decimal point, subdivision can be continued indefinitely.

The U.D.C. has been adopted for many years by the International Institute of Bibliography at Brussels, at present the International Institute for Documentation. This Institute has undertaken to keep the system up to date by publishing additions and further developments in supplements to the existing codes.

As a matter of fact, the U.D.C. has already made room for Oceanography under number 551.46 and partly also under number 551.35, but the existing classification does not seem to meet

the practical requirements. For this reason it is suggested that an entirely new classification on the U.D.C. principles be devised to replace the existing section. This can be done most effectively by a small committee.

A draft classification will be submitted as an appendix to this proposal.

E 1. *Tidal Observatories on the Indo-Pakistan-Burma-Siamese Coast*

Tide-gauge operations in India started as early as 1873 or so, with the object of settling the controversy raging at that time that the Kathiawar coast and the land near the Rann of Kutch were in a state of gradual subsidence. Soon after, a number of tide-gauges were installed all along the coast for the purpose of providing material for harmonic analysis for tidal predictions. Due to financial and other reasons most of the observatories stopped functioning before the end of the last century and along the 6500 miles stretch of coast of Pakistan, India, Burma and Siam only three active tide-gauge observatories are in operation at present, and out of these one is on a riverain port. Considering the fact that there are areas of considerable interest along this coast-line, such as the Rann of Kutch, delta of Bengal, Burma and Malaya Coast, which are suspected by the geologists to be subsiding gradually, it appears imperative to set up more tide-gauge observatories well spaced along the whole coast. It is therefore proposed that the resolution may be placed before the International Union of Geodesy and Geophysics for consideration at the meeting to be held at Oslo.

Reports of Meetings

First General Meeting of the Association

Friday, 20th August 1948

The Meeting opened at 14.30, when the Chair was taken by the President, Professor SVERDRUP. Seventy-five delegates and guests were present.

A. The PRESIDENT gave his Address on "The wind and the sea" (see pp. 37–55).

The Assembly then agreed, unanimously, to send the following telegram to Dr. WAYLAND VAUGHAN, Washington, D.C.:

"The International Association of Physical Oceanography in General Assembly at Oslo sends warmest greetings to Dr. Wayland Vaughan and best wishes for his health.

SVERDRUP."

Second General Meeting of the Association

Monday, 23rd August 1948

The Meeting opened at 10.00, when the Chair was taken by the President, Professor SVERDRUP. Thirty-six delegates and guests were present.

The PRESIDENT asked the delegates from each country to choose one of their number to vote on administrative and financial questions, in cases in which the choice had not already been made by national authorities.

It was agreed unanimously to consider those items of the Agenda which had not been circulated four months in advance.

G 1. Vice-Admiral NARES read his "Report on the work carried out by the International Hydrographic Bureau" (see p. 86).

G 5. Professor L. TISON read the report by J. Lamoen on "Travaux effectués en Belgique de 1939 à 1948" (see p. 100).

Professor THIJSSE said: "I should like to make sure whether this most interesting problem of the propagation of tides in estuaries and tidal rivers—observation, experiments and theory—belongs to Oceanography or to Hydrology."

Professor PROUDMAN said: "As the tides are mainly generated in the great ocean basins, it is convenient for oceanographers to study tide phenomena in rivers. It is better to be inclusive, and no harm is done by a little overlapping in the subjects studied by two Associations."

Professor Fjeldstad, Dr. Doodson, Captain Meaney and the President agreed with this.

G 8. The SECRETARY read the report by N. Menendez on "A preliminary oceanographic campaign in the Sea of Alborán" (see p. 111).

G 9. Copies of the report by K. HIDAKA on "Activities in physical oceanography in Japan since 1939" were distributed to delegates and guests.

The items of the Agenda *G* 3, 3.1, 4, 4.1, 6, 6.1 were received in Abstract (see pp. 89–106).

Third General Meeting of the Association

Monday, 23rd August 1948

The Meeting opened at 14.30, when, at the request of the President, the Chair was taken by Dr. DEACON. Thirty-four delegates and guests were present.

H 7. Professor PROUDMAN read his paper on "The theory of mixing of sea-water through turbulence" (see p. 142).

H 9.1. Dr. DIETZ read his paper on "Deep scattering layers in the Pacific and Antarctic Oceans" (see p. 149).

Dr. FLEMING said:

"(1) A scattering layer was observed but not explained by Dr. J. Anderson in 1932 (H.M. Under-Water Detection Establishment, Portland).

(2) The absence of a layer does not imply the absence of scatterers. Diffuse scattering will not be detected on the record except as a general greyness of the record.

(3) Biologists must develop means for catching pelagic fishes and squids before the full implication of the phenomena can be evaluated."

Dr. MACKINTOSH said: "Pelagic organisms are generally found to have a discontinuous distribution, whereas the scattering layer is continuous over great distances. However, it should be possible, by means of net hauls, in due course to decide whether or not the plankton is the cause."

Dr. F. S. RUSSELL said: "Does the deep scattering layer remain at one depth from soon after sunrise until the beginning of the ascent at sunset? If so, this would indicate the presence of a barrier if plankton animals are the cause, because they would be expected to follow a flattening descending curve till after midday and then slowly rise."

Dr. DIETZ replied: "The deep scattering layer often changes depth during the day, but the maximum depth is not necessarily at noon. The normal daylight depth appears to be usually

reached shortly after sunrise, from which depth departures are relatively small."

Dr. STEPHENSON said: "In 1933, on a U.S. Navy trip from Panama to San Diego, a scattering layer was detected both day and night, starting at 25–30 fathoms at Panama and gradually increasing in depth until it was lost off the coast of Nicaragua at 150–200 fathoms. This corresponded to a temperature boundary between warm surface-water and cold Humboldt Current at Panama, where temperature measurements were made. No temperature measurements were made later. The depth of water was 2000 to 2800 fathoms. Sound reflection was *assumed* to be from the steep temperature-gradient."

Lieutenant-Commander LUMBY said: "What was the shallowest depth of water in which the scattering layer was observed? Is it confined to the oceans only? Dr. Dietz's records show very continuous layers and their intensity suggests a very high concentration indeed of organisms—'scatterers.' Is this a technical matter connected with the type of machine used?"

Dr. DIETZ replied:

"(1) Layers of scatters are found at very shoal depths. However, the main and usually present scattering layer, which I refer to as the *deep* scattering layer, we noted from 125 to 450 fathoms. I know of no records from the scattering layer in bodies of water other than the ocean.

(2) If the organisms are close together, a relatively low concentration of the order of 1 cm.^{3} of scatterer per m.^{3} of water might cause the observed scattering. The deep scattering layer appears to be usually continuous over large distances."

Professor REVELLE said: "A very low concentration of scattering substances is required to give the observed echoes from the deep scattering layer; as I recall: less than about 10^{-6}, that is 1 cm.^{3} per m.^{3}"

H 9.2. Dr. DANA RUSSELL read his paper on "SOFAR, a new oceanographic research tool" (see p. 150). He illustrated it by means of a film and a gramophone-record of sounds from distant explosions in the sound-channel.

Professor REVELLE said: "The sound transmission over

great distances attained in the SOFAR system is perhaps chiefly due to the extremely small attenuation of low-frequency sound within the sound channel and the absence of losses of sound energy in the surface-layers and in the bottom-sediments, which result from the bending of the sound rays away from the surface and the bottom. With regard to the efficiency of SOFAR in high latitudes, the absence of a sound channel certainly raises doubts, but the small attenuation of low-frequency sound referred to above may make it possible to receive signals over very considerable distances, provided that some means of recognizing the signals can be found."

Dr. MUNK said: "The depth of the sound channel decreases with latitude, and actually reaches the surface. This makes the usefulness of SOFAR in high latitudes uncertain."

Dr. WISEMAN asked: "Could Dr. Dana Russell please say whether the SOFAR system could be used for the accurate position-finding of a ship in mid-oceanic regions, so that a detailed topographical chart could be made of a sea-mount."

Dr. DANA RUSSELL replied: "This would not be a very practical use, as a delay of an hour or more would ensue before the fix could be obtained and radioed to the ship. The accuracy of location is approximately within 10 miles for the preliminary fix by chart; this takes only a few minutes. A more accurate fix, using correction formulæ and tables, reduces the radius of the error to about one mile; these calculations take $\frac{1}{2}$ to 1 hour at present."

G 9.1. In reference to the Abstract submitted by E. C. La Fond on "Thermal structure of the surface layers of the sea near the Antarctic Convergence" (see p. 115), Dr. DIETZ said: "Mr. La Fond's paper concerns the temperature structure shown by some bathythermal records obtained while crossing the Antarctic Convergence. The crossings were made (1) in the eastern Pacific–Antarctic, (2) in the central Pacific-Antarctic north of the Ross Sea, and (3) in the Indian Ocean-Antarctic."

The item of the Agenda *G* 9.2 was received in Abstract (see p. 116).

Fourth General Meeting of the Association

Tuesday, 24th August 1948

The Meeting opened at 10.00 when, at the request of the President, the Chair was taken by Professor FJELDSTAD. Forty delegates and guests were present.

D 1. Professor PROUDMAN submitted the Report of the Committee on Tides (see p. 71). This report was adopted unanimously, and it was decided to publish the Bibliography on Tides as recommended in the report.

C 1. It was agreed that, for the next period, the constitution of the Committee on Tides should be as given on p. 69.

H 2.1. Monsieur GOUGENHEIM read the paper by H. Lacombe: "Étude sur la marée de la Manche centrale" (see p. 127).

Dr. DOODSON said: "The variations in shape of tide-curves in the Channel may be simply explained by the fact that the nodal line of the semidiurnal tide passes through the Isle of Wight, whereas the nodal lines of the quarter-diurnal tide lie between the Isle of Wight and Dover, and to the west of Portland. The phase of the semidiurnal tide changes quickly, that of the quarter-diurnal tide slowly, so that at high water at Portland the two species are in phase, whereas at Southampton they are 180° out of phase. But the full explanation is rather more complex than this."

Dr. CARRUTHERS asked: "Did Monsieur Gougenheim and his colleagues base their work now described on existing observations of tidal streams, or had they carried out new ones specially?"

Monsieur GOUGENHEIM replied that they had used the observational data arising from the Franco-British collaboration in force just before the War.

Professor THIJSSE asked: "If the disparities between Cherbourg and Barfleur can be explained by frictional resistance on the bottom of the relatively shallow water."

Monsieur GOUGENHAIM replied: "Le frottement sur le fond ne suffit pas à expliquer la discordance attachée aux abords de Barfleur. Elle provient surtout du fait que dans cette région on ne peut plus confondre du/dt avec $\partial a/\partial t$, en négligeant les termes rectangles $u\partial u/\partial x + v\partial u/\partial y$ qui dépendent de la direction et de la grandeur de la vitesse instantanée des particules. Il faudrait des stations de courant assez serrées pour pourvoir évaluer ces termes en vue d'en tenir compte dans les parages où la vitesse du courant varie rapidement en grandeur et direction."

F 4. Professor PROUDMAN referred to the Abstract of his paper "On the applicability of Laplace's differential equations of the tides" (see p. 84), and proposed that a fuller discussion be postponed.

F 3. Professor THIJSSE read his paper on "Dimensions of wind-generated waves" (see p. 80).

Dr. DEACON read his paper on "The decay and growth of waves" (see p. 82).

Professor SVERDRUP congratulated Dr. Deacon on the results of his studies. Regarding the simultaneous increase of wave-length and wave-height, Professor SVERDRUP wanted to point out that the assumption that part of the wind energy goes towards increasing the wave-length and part towards increasing the wave-height was an assumption *ad hoc*. It may have some physical basis because it leads to rational results, but that basis is obscure. According to present concepts, a wave-spectrum is generated by the wind. As the wind blows over the water the longer waves in that spectrum absorb more and more energy, meaning that the region of maximum energy (maximum wave-height) is shifted towards greater wave-lengths. This process leads to apparent increase in wave-length.

Mr. BARBER concurred with Professor Sverdrup that it was desirable to think of a spectrum of wave-periods in order to get a physical idea of the growth of waves. If one imagines that only a single period is present, one is forced to conclude that numbers of individual wave-crests disappear as they move across the wind-area.

Dr. MUNK said: "Recent studies by the Department of Engineering of the University of California deal with the effect

of friction on waves entering shallow water. On beaches of slopes more than 2 per cent. this effect is negligible. It has been demonstrated that theoretically computed losses by frictional dissipation along the bottom are consistent with the observed effects on wave-height."

Professor THIJSSE said: "In the experimental flume the waves can be observed through the glass side walls. Continuous records have been made of the variation in water-level at a given point. Of course this gives a spectrum of waves, but there is always one outstanding wave-period at every place. Travelling with the wind, this period increases so that the number of 'outstanding' waves diminishes as the fetch increases. The impression is created that waves actually disappear."

H 4·1. Mr. BARBER read his paper on "Recent studies of waves and swell" (see p. 135).

Professor PROUDMAN recalled the investigations of Sir George Stokes in 1878 on the generation of swell by storms ("Memoir and Scientific Correspondence," vol. 2, pp. 141–153).

H 4. Dr. MUNK read his paper on "Spectrum of gravity waves in the sea" (see p. 134).

Professor FJELDSTAD enquired as to the period of seiches which might be observed at the place of installation of the instrument described by Dr. Munk. Dr. MUNK replied that the period was about four minutes.

Professor PROUDMAN pointed out that the shorter-period shallow-water tidal constituents came within the range considered by Dr. Munk.

Dr. DOODSON enquired if any waves of periods near to three hours had been observed, as he was informed that in many observations of tidal currents waves of these periods occurred without any obvious tidal explanation.

Mr. BARBER thanked Dr. Munk for his most interesting paper, and asked: "Is it possible that pressure-disturbances may exist in the atmosphere, travelling at speeds near to 600 knots, and serve as a generator of waves of period 15 minutes? The existence of waves of period 2–10 minutes was proposed by Stewart (University of Capetown) as a cause of 'range' in Table Bay harbour, but no direct measurement of these waves was made."

Professor SVERDRUP suggested that the orientation of fronts may have a bearing on the arrival of the fifteen-minute waves.

H 5. Professor THIJSSE read the paper by P. Groen entitled: "Note on the properties of internal waves" (see p. 137).

The item *H* 2 of the Agenda was received in Abstract (see p. 125).

Fifth General Meeting of the Association

Wednesday, 25th August 1948

The Meeting opened at 10.00, when the Chair was taken by the PRESIDENT. Twenty-two delegates and guests were present.

B 1. The Secretary submitted his Report for the period 1939–48 (see pp. 57–59). This was adopted unanimously.

B 2. The Secretary submitted the Financial Report for the period 1939–47 (see pp. 60–62). This was adopted unanimously.

B 3. The Secretary submitted the following Financial Estimates for the period 1948–51, which had been prepared by the Executive Committee.

Average Expenditure for each Year

Cost of publications, preparation and printing .	£500
Cost of preparation of standard sea-water .	350
Cost of Association Bureau	50
	£900

These Estimates were adopted unanimously.

B 4. The Secretary submitted a draft of new STATUTES and BY-LAWS which had been circulated in accordance with the Statutes adopted in 1933. Two changes were made in this draft and then the Statutes and By-laws were adopted unanimously in the form given on pp. 63–68.

B 5. The Assembly then proceeded to the election of new OFFICERS and EXECUTIVE COMMITTEE in accordance with the new Statutes and By-laws. The President reported that, some days earlier, he had appointed a NOMINATING COMMITTEE, consisting of Dr. Carruthers and Professor Fjeldstad, to make nominations for the offices and membership of the Executive Committee.

On behalf of this Nominating Committee Dr. Carruthers then made nominations. Two further nominations for membership of the Executive Committee were made by delegates. The new officers were then unanimously elected as given on p. 69, and the voting delegates from each adhering country then proceeded to select four names from the six nominees for the Executive Committee. The Nominating Committee examined the voting papers and reported the result of the election to be as given on p. 69.

D 3. The Secretary reported that the Chairman of the Committee on Chemical Methods and Units recommended that this committee should not be reappointed, but that the remaining work for which it had been appointed should be carried out by the Committee on the Preparation of a Technical Handbook.

C 3. The Assembly agreed unanimously to do this.

D 4. As no report had been submitted by the Committee on Criteria and Nomenclature for the Major Divisions of the Ocean-bottom, it was decided to appoint a temporary committee as follows:

R. H. Fleming,
J. D. Nares,
R. R. Revelle,
J. B. Tait,

to consider the question of the reappointment of this Committee.

D 5. Dr. Fleming submitted the Report of the Committee on oceanographical observations from Atlantic weather-ships (see p. 74). This Report was adopted unanimously.

C 5. It was then agreed unanimously that the constitution of the Committee on oceanographical observations from Atlantic weather-ships should be as given on p. 70.

D 6. Professor Sverdrup submitted the Report of the Committee on the Preparation of a Technical Handbook (see p. 76). This report was adopted unanimously.

C 6. It was agreed unanimously that the Committee on the Preparation of a Technical Handbook should be reappointed as given on p. 70.

D 7. No report was submitted from the Joint Committee of the Associations of Physical Oceanography and Meteorology on questions of interaction between the sea and the atmosphere.

C 9. It was agreed unanimously that the Association of Physical Oceanography should not appoint new members of this Joint Committee.

C 7. 8. It was agreed unanimously to appoint a committee, with the constitution as given on p. 70, to consider the general questions arising on the preparation of a bibliography on oceanography. The appointments of L. Fage, J. R. Lumby and J. Ruud were made on the nomination of the Joint Commission on Oceanography.

E 1. It was agreed unanimously to recommend to the General Assembly of the Union the resolution proposed by Mr. Gulatee and given on p. 56.

E 1.1. The Assembly considered the question of passing a resolution on the desirability of a geophysical survey of the Great Barrier Reef of Australia. As no details were submitted no such resolution was passed.

The Secretary read a letter from the Secretary of the Joint Commission on Oceanography, asking for support in an application to UNESCO for financial assistance to be given by UNESCO to the Oceanographic Institute at Monaco.

It was agreed unanimously to recommend to the General Assembly of the Union the resolution as given on p. 56.

The item of the Agenda *H* 8 was received in Abstract (see p. 144).

Sixth General Meeting of the Association

Thursday, 26th August 1948

The Meeting opened at 10.00, when, at the request of the President, the Chair was taken by Monsieur GOUGENHEIM. Thirty-six delegates and guests were present.

H 9. Dr. DOODSON read his paper on "A study of storm-surges in the North Sea" (see p. 148).

Professor PROUDMAN recalled his dynamical explanation of a surge which had occurred on the south coast of England on 20th July 1929 (C. K. M. Douglas, *Meteorol. Mag.*, vol. 64, pp. 187–189).

Mr. BARBER said: "The eddy-viscosity appears to be in good agreement with values obtained from wind-produced currents, though these values cannot be tolerated for waves. Perhaps the turbulence has different effects on motions of different scales of wave-length."

Dr. DOODSON replied: "The value of 500–700 cm.^{2}/sec. for the coefficient of eddy-viscosity, associated with the decay-factor, was obtained by the first theory. When a travelling disturbance is considered possible the observed surges would be suited by a much higher coefficient, 2000 cm.^{2}/sec. or more."

Professor SVERDRUP said: "The value of the eddy-viscosity is related to the scale of the phenomenon. The value 500–1000 cm.^{2}/sec. appears reasonable, but that value is not applicable to such small-scale phenomena as surface-waves. What quantity was used to represent the wind-effect?"

Dr. DOODSON replied: "The barometric gradients were used to give estimates of mean wind."

Dr. DEACON said: "Is there any evidence, when the barometric gradients and other conditions are the same, that the wind has a greater effect in winter than in summer? I ask the question because of my interest in the statement often made by experienced seamen that the same amount of wind raises greater storms in cold water than it would in warm water."

Professor FJELDSTAD said: "The eddy-viscosity will probably be greater in winter than in summer, because the stability is usually less in winter than in summer. This is indicated by investigations on the transport of heat in the Biscay region."

Captain MEANEY said: "Dr. Doodson referred to the loss of life caused by storm-surges. Has he investigated the possibility of predicting the time when dangerous storm-surges will occur?"

Dr. DOODSON replied: "It is hoped to set up, at the Liverpool Tidal Institute, an organization which will give daily forecasts for the Thames. There is an organization in Germany, of which Dr. Carruthers will be able to give more particulars."

Dr. CARRUTHERS said: "There is in Germany an elaborate organization for issuing warnings of storm-surges such as can bring floods and other disasters to Hamburg and its vicinity. Close liaison with the Post Office Authorities allows for rapid dissemination of the warnings made by the co-operative effort of tide specialists and metorologists."

H 3. Dr. CARRUTHERS read his paper on "A new method of continuous current measuring from an unattended buoy (see p. 130).

Professor WERENSKIOLD asked: "Is it possible to construct a current-meter, held in direction by a strong magnet and with two propellers giving the E.-W. and the N.-S. components of the velocity?"

Lieutenant-Commander LUMBY said: "I should like to emphasize certain advantages given by Carruthers's new instrument. As it can be moored away from lightships, research vessels, etc., no uncertainty arises from the magnetic field of the ship. Secondly, earlier types of meter, suitable for the open sea and giving long period records, usually provided integrated values of the current, and it is a very useful attribute that the present meter gives individual records which may be used for some examination of the nature of the water movement."

H 3.2. Professor MOSBY read his paper on "Experiments on bottom-friction" (see p. 133).

Mr. BARBER asked: "Is the apparatus troubled by seaweed?" and Professor MOSBY answered: "Yes."

Mr. BARBER then said: "Two unexpected results are:

(1) that the oscillations of velocity of period 1 minute appear to be about 15 seconds earlier on the higher than on the lower instrument;

(2) that the changes in the tidal stream velocity at the bottom seem to lag rather than to lead the upper layers, as theory would suggest."

Professor MOSBY agreed that this was the case.

Mr. BARBER then asked: "Could the oscillations of velocity suggest a value for turbulent viscosity to be related to the velocity-gradient observed?"

Professor MOSBY replied: "The observations are not suitable because they relate to horizontal velocities only."

Mr. WALDO SMITH said: "The cup type of current-meter is especially susceptible to the effects of turbulence, eddies and cross-currents, and thus the velocities recorded are really a measure of the magnitude of the horizontal velocity, or rather, the scalar value or horizontal speed. I want to enquire in what way are these data used quantitatively, such as for the determination of flow, and, if so used, what adjustment is made for cross-flow and turbulence."

H 3.1. Professor FJELDSTAD read the paper by O. DAHL and himself on "A new repeating current meter" (see p. 131), and gave a demonstration on an actual instrument.

H 6. Professor EKMAN read his paper on: "Turbulent, periodic and mean motions; some measurements in the Atlantic by B. Helland-Hansen and the Author" (see p. 139).

Dr. DOODSON said: "There could only be a minute lunar diurnal tide M_1, but in June–July K_1 and P_1 would be in phase owing to high solar declination, and therefore would be predominant in the diurnal tide. The period would thus not be 24 hr. 50 min. but rather less than 24 hr."

Professor MOSBY supported the view of Professor Ekman that the quasi periods of duration from 6–48 hours may be regarded as a sort of macro turbulent fluctuations. Comparing with the small-scale investigations at Alværströmmen, where

the fluctuations lasted from 2–15 minutes, the complete series of 4–5 hours' duration would, in Ekman's case, correspond to a series of measurements covering at least one month. If such series were available, it certainly might be expected that the non-periodic nature of the fluctuations in question would come out much more clearly."

Dr. MUNK said: "The questions raised by Professor Ekman's paper may have a bearing on two recent unpublished papers by Heisenberg and Weizsäcker in Germany. These papers derive theoretically the dependence of the turbulence coefficients on the scale of the phenomenon involved, leading to large values for large-scale phenomena and to small values for small-scale phenomena. The results bear out an empirical relationship previously derived by L. F. Richardson. It may be hoped that this will lead to a substantial reduction in the apparently random scatter of turbulence coefficients previously computed and make possible an evaluation of the rôle played by wind, vertical stability and other factors."

Dr. DEACON said: "One of my colleagues, Mr. F. Ursell, in theoretical work on the form of swell on a rotating earth, has shown that a water particle at the surface will travel *cum sole* round a circle whose radius depends on the wave-length and the sine of the angle of latitude, describing the circle in half a pendulum-day. The radius in mid latitudes is of the order of 500 metres. Such a movement has still to be observed, and is not likely to contribute appreciably to the oscillations described in Professor Ekman's paper, but its possible effect on the transport of the surface-water or the movement of an anchored ship should be borne in mind."

Seventh General Meeting of the Association

Thursday, 26th August 1948

The Meeting opened at 14.30, when, at the request of the President, the Chair was taken by Professor PROUDMAN. Twenty-four delegates and guests were present.

D 2. Professor PROUDMAN submitted the Report of the Committee on mean sea-level and its variations (see p. 72). This report was adopted unanimously, and it was agreed to publish a volume of data as recommended in the report.

C 2. It was agreed unanimously that the constitution of the Committee on mean sea-level and its variations should be as given on p. 70.

H 1.1. Captain MEANEY read his paper on "Mean sea-level as a geophysical datum" (see p. 121).

Dr. FLEMING asked: "Is the rise in sea-level on the east and west coasts of North America since 1930 a world-wide phenomenon?"

F 2. Vice-Admiral NARES read his paper on "Extension of the network of tidal stations of the world" (see p. 79).

F 4. Professor PROUDMAN read his paper on "The applicability of Laplace's differential equations of the tides" (see p. 84), which had been postponed from the Third General Meeting.

The items of the Agenda *G* 7 and *H* 1 were received in Abstract (see pp. 108, 119).

Eighth General Meeting of the Association

Friday, 27th August 1948

The Meeting opened at 10.00, when, at the request of the President, the Chair was taken by Dr. CARRUTHERS. Thirty delegates and guests were present.

G 2. Vice-Admiral NARES read his "Report on the preparation of the third edition of the General Bathymetric Chart of the Oceans" (see p. 88).

The Secretary recalled that in 1935 this Association made a grant of £100 towards the cost of producing the Chart.

Dr. FLEMING said: "The vast number of soundings now becoming available through the use of echo-sounders appears to render the work of the International Hydrographic Bureau in the preparation of bathymetric charts completely inadequate. It had been suggested that various national hydrographic offices should assume the responsibility for at least the plotting of new data in designated areas."

Professor SVERDRUP asked if the preparation of bathymetric charts could be supported financially by UNESCO, and the Secretary replied that it could. Professor Sverdrup went on to say that the preparation of the charts was primarily a matter of scientific interest and hoped that financial support could be obtained from scientific sources.

Monsieur GOUGENHEIM said: "Le Service Hydrographique de la Marine à Paris a demandé à plusieurs organismes scientifiques français at à des Services publics interessés par la Carte Bathymetrique des Océans, d'accorder si possible une subvention financière au Bureau Hydrographique International pour l'aider à achever la publication de la troisième édition de cette Carte."

F 1. Vice-Admiral NARES read his paper on "Limits of oceans and seas" (see p. 78).

Dr. DEACON said: "I suggest that this question be left entirely to the Hydrographic Offices. An oceanographer will

use their precise names when he can, but in describing the distributions of physical properties and plant and animal populations, which do not conform to prominent geographical features and may have seasonal and annual changes, he must be allowed some latitude; nor can his general bio-geographical limits be acceptable to the Hydrographic Offices."

Dr. MACKINTOSH agreed with Dr. Deacon.

Professor SVERDRUP disagreed with Dr. Deacon, believing that, when possible, oceanographers should use the accepted geographical names. Also, it might be worth while trying to make oceanographic and geographic limits coincide whenever possible."

H 8.1 Professor SPILHAUS read his paper on "Bathythermograph sea sampler" (see p. 146).

Professor MOSBY said: "I have been planning to design some instrument for obtaining exactly simultaneous values of temperature and salinity in connection with the thermosounder. The water sampler of Spilhaus may be used for this purpose when altered so as to be operated not by pressure but by the propeller of the thermosounder. At the greater depths here in question the vertical gradients are so small that the equivalent length of the sampler will probably be sufficiently small."

D 4. Dr. TAIT read the Report of the Temporary Committee set up to consider the question of reappointment of the Committee on criteria and nomenclature for the major divisions of the ocean-bottom (see p. 73).

Professor REVELLE said: "Because of the great importance to submarine geology and the other earth-sciences of an up-to-date uniform bathymetric chart of the oceans, the Association of Physical Oceanography should, in my opinion, use every means at its disposal to further the preparation of such a chart. On the other hand, the number of soundings has increased so greatly with the introduction of echo-sounding that it has probably become impossible to show actual depths of every sounding, and the data must be presented essentially by contours of equal depth. The drawing of contours is by no means an easy or routine matter, and should be carried out in accordance with principles established by the experience of submarine

geologists. It is evident that the scientific and economic problems involved cannot be settled in the limited time at our disposal at this General Assembly of the Association. I therefore propose that these problems be referred to the Committee on Nomenclature of Ocean Bottom Features and that the title and functions of the Committee be extended accordingly. The name of the Committee should be changed to 'Committee on presentation and nomenclature of ocean bottom features', and its function should be extended to include the development of methods and arrangements for presentation of data on ocean bottom topography."

The recommendations of the Report of the Temporary Committee were adopted with the following additions:

(1) to add K. O. Emery to the list of members of the Committee;

(2) to add to the terms of reference of the Committee: "to consider methods of presentation of marine topographical data on bathymetric charts."

H 7. Professor PROUDMAN gave an expanded treatment of that part of his paper on "The theory of the mixing of seawater through turbulence" which referred to the Irish Sea (see p. 142).

The CHAIRMAN referred to the termination of Professor PROUDMAN'S fifteen years' tenure of office as Secretary of the Association, and the General Assembly tendered to Professor Proudman their cordial thanks.

Presidential Address

The Wind and the Sea

By
H. U. SVERDRUP

Summary

The stress which the wind exerts on the sea surface contributes to the growth of waves, produces temporary wind currents and supplies the energy needed for maintaining the permanent currents of the oceans.

Measurements of wind profiles over the sea and other types of measurements have led to the establishment of quantitative relations between wind and stress. These relationships have now been successfully applied to other problems.

The growth of waves has been accounted for, taking the effect of the wind stress into account. The pure wind current has been dealt with, but measurements are not available for examining the quantitative relationships between the wind stress and the pure wind current.

For the North Pacific, charts of the wind stress and the permanent currents are in excellent qualitative agreement. In the eastern equatorial Pacific the Equatorial Counter Current can be accounted for, and in this case a satisfactory quantitative agreement is obtained between the pressure distribution in the sea as derived directly from oceanographic observations and indirectly from the wind stress, which in turn has been computed from climatological wind data.

1. Introduction

Members of the International Association of Physical Oceanography and Guests.—It is my honour and privilege to welcome you to the opening of this eighth General Assembly of our Association and to express the hope that our meetings will be interesting and mutually beneficial.

Oceanography is now in a state of rapid expansion, with new ships being commissioned, new laboratories being built, and programmes of instruction being expanded. When viewing this activity we have to bear in mind that our Association represents the only fully international organization in our field and that in the coming years the discussion of technical questions may take more and more of our time. On an earlier occasion I have pointed out (Sverdrup, 1947 *a*) that it even may become necessary to establish an independent technical organization which in particular will have to deal with matters of international co-operation of interest to government agencies concerned with oceanography. One may visualize a development comparable to that which has taken place in meteorology, where technical and scientific international bodies exist with overlapping memberships.

In our field we may experience still another development. On the initiative of the Union of Biological Sciences there has been created an International Mixed Commission on Oceanography with representatives of various branches of marine biology as well as of physical-chemical oceanography. The establishment of this commission expresses the need for international co-operation within the broad fields of all marine sciences and out of this commission there may grow an International Union of Oceanography. If this happens, we can expect that many of our members will also join such a Union, but otherwise the developments should not alter the status of our Association. We shall always need it in order to remain in contact with the other geophysical sciences and in order to present and discuss our special scientific problems.

After the long interruption in international co-operation it might have been tempting to use this occasion for a review of the developments in physical oceanography during the nine

years that have elapsed since we last met. These developments include not only applications of earlier findings to many military problems, but also intensive research within previously neglected fields of oceanography, as well as design and use of new types of instruments. It is so varied that in a general address the mentioning of all phases would easily take the form of a mere enumeration, and it is, therefore, better dealt with in the special sessions. Here I shall confine myself to a brief discussion of one of the central topics in physical oceanography: the effects of the wind—hoping that I can present some recent results and offer some suggestions for further studies.

The most obvious effect of the wind on the waters is that the wind raises waves, ranging in dimensions and force from gentle ripples to billowing, roaring seas, which may continue as swell over wide ocean areas until they break against distant coasts. Furthermore, the wind produces temporary wind currents, and in addition more and more evidence is being accumulated to show that the large-scale, permanent currents of the oceans are being maintained by the average wind conditions.

The circulations of the atmosphere and the oceans cannot be dealt with independently, but have to be treated as two parts of one system. The one part, the atmosphere, can be considered a thermodynamic machine in which on an average so much heat is converted into mechanical energy that the dissipation by friction is offset. Some of this heat is derived by direct absorption of radiation, but a great amount is conducted to the atmosphere from the ocean or released by condensation of water vapour which has been supplied by evaporation from the sea surface. The permanent currents of the oceans, on the other hand, are maintained mainly by the effect of friction, that is by the stress exerted by the wind on the water surface. The details of the currents depend on the stratification of the upper layers, which in turn is related to effects of processes of heating and cooling, but the energy needed for maintaining the flow is largely derived from the winds. Knowledge of the wind stress is, therefore, all important to a quantitative evaluation of the effects of the wind.

2. The Wind Stress

The most remarkable result of recent studies is that at low wind velocities the sea surface has the character of a hydrodynamically smooth surface whereas at higher winds it behaves as a hydrodynamically rough surface. In both cases the relation between the stress, τ, and the wind velocity, u, can be written in the form (Taylor, 1916):

$$\tau = \gamma_z^2 \rho u_z^2, \tag{1}$$

where ρ is the density of the air, u_z is the wind velocity at the height z above the surface, and γ_z^2 is called the resistance coefficient. The latter is a pure number, the value of which depends upon the height, z, at which the wind velocity is measured, and upon the character of the surface, whether smooth or rough.

On the basis of experiments in the laboratory, v. Karmán (1934) found that the resistance coefficient over a smooth surface is obtained from the equation:

$$\frac{1}{\gamma_z} + \frac{1}{k_0} ln \frac{1}{\gamma_z} = 5{\cdot}5 + \frac{1}{k_0} ln \frac{u_z z}{\nu}, \tag{2}$$

where ν is the kinematic viscosity of the air, and where k_0, v. Karmán's constant, equals 0·4.

According to Prandtl and slightly modified by Rossby (1936) the resistance coefficient over a rough surface is given by:

$$\gamma_z^2 = \left(\frac{k_0}{ln\left(\frac{z + z_0}{z_0} \right)} \right)^2, \tag{3}$$

where z_0 is a length that characterizes the roughness of the sea surface.

In applying the laboratory results to conditions over the ocean Rossby arrived at the conclusion that at a wind velocity between 6 and 8 m./sec. as measured at a height of about 8 m. the character of the sea surface changes abruptly from smooth to rough, and that, consequently, the resistance coefficient increased abruptly. At this critical wind speed a number of other changes occur, the evaporation coefficient, which will not be defined here, increases abruptly, white caps (white horses)

appear and the sea-gulls change their soaring tactics from soaring in circles to soaring in straight lines (see fig. 1).

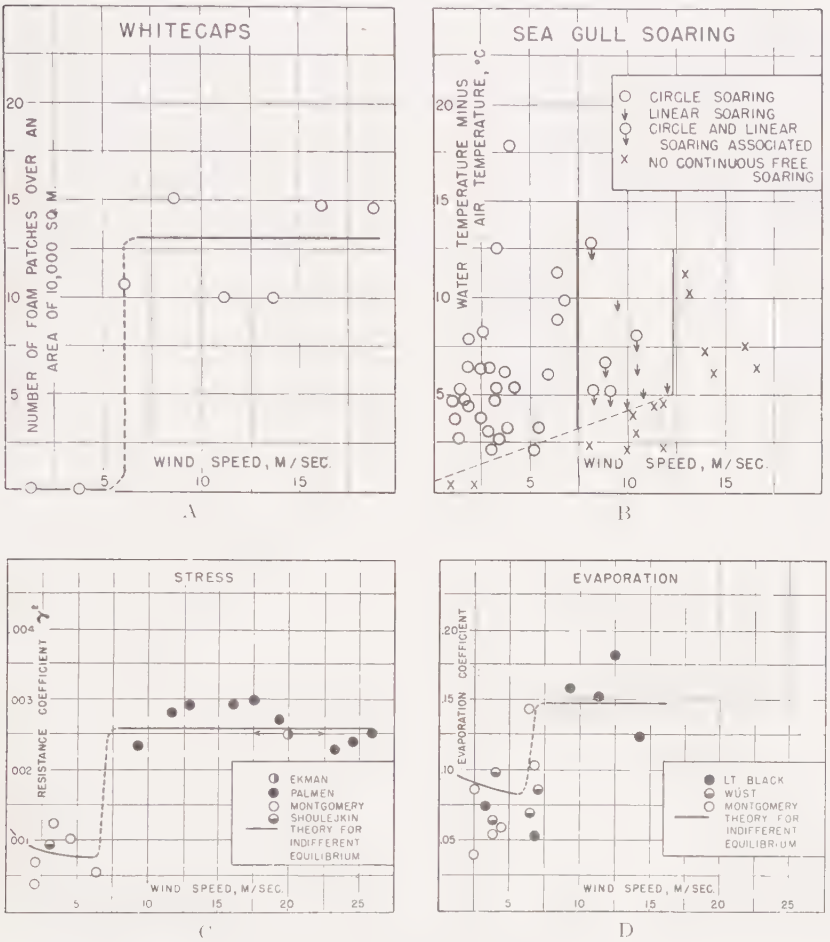

Fig. 1. (After Munk, 1947)

A. The occurrence of white caps (white horses) at different wind velocities.
B. Soaring tactics of sea-gulls (after Woodcock).
C. The resistance coefficient as a function of the wind velocity.
D. The evaporation coefficient as a function of the wind velocity.

Munk (1947) has pointed out that the critical wind speed coincides closely with the wind speed at which, according to Helmholz and Lord Kelvin, the capillary wavelets at the sea surface become unstable. This speed lies at about 6·6 m./sec.

and varies only slightly with the temperature of the air and the water. When capillary waves are formed at wind speed below the critical limit they diminish and die out. With the wind speed above the critical limit the capillary waves grow so rapidly that their form soon becomes unstable and the smooth wave contours are changed into series of sharp ridges. This change must have a profound effect on the turbulence directly above the water surface. As long as the smooth-wave forms prevail, a laminar layer exists within which the air flows smoothly over the water, but when the sharp ripples develop, the air flow becomes turbulent at the very surface. Consequently, the grip of the wind on the water increases, leading to an abrupt increase in the resistance coefficient, and to a number of other consequences. The energy transfer from the air increases, with the result that the larger waves grow so rapidly that they break and white caps appear, and the changed turbulence is reflected even in the manner in which the sea-gulls make use of the gustiness of the wind.

All available data indicate that above the critical speed the resistance coefficient is independent of the wind velocity, which implies that the roughness length of the sea surface remains constant. This implication appears at first glance unreasonable, because the stronger the wind blows the larger are the waves and the more irregular is the sea surface. However, the larger waves move nearly with the velocity of the wind and may, therefore, be of small importance to the turbulence of the air. The latter is probably dependent upon the small ripples which at wind speeds above the critical limit give the sea surface its corrugated appearance. Still, the roughness length is surprisingly small, having a value of about 0·6 cm.

The quantitative relation between wind and wind stress, which has been discussed, has been established by examining the variation of wind velocity with the height directly above the sea surface (Rossby, 1936) and by analysing the piling up of water by the wind, particularly in the Baltic and the Gulf of Bothnia (Ekman, 1905, Palmén and Laurila, 1938). The results have been substantiated by the successful application to other problems, which will be further discussed, but other

interpretations of the observed conditions are possible (*e.g.* Model, 1942), for which reason further studies, particularly of the wind profile over the sea, are highly desirable.

3. Growth of Waves

The first application of the relation between wind and stress pertains to the growth of waves under the influence of the wind. The first formation of waves is not yet fully understood, but it seems more and more probable that waves are impulsively generated by the gustiness of the wind, or even by the accompany- short oscillations of the atmospheric pressure. If so the waves are similar to those produced when a stone is thrown in the water. When waves are generated in this manner an entire spectrum of waves is formed, that is, waves are produced of a great variety of periods and corresponding lengths (Barber and Ursell, 1948). Of the waves raised by the wind, the shortest waves grow the fastest, but with a strong wind these soon attain such steepness that they become unstable and break, whereas the longer ones continue to grow. The very longest ones do, however, not grow, because they travel very much faster than the wind. With a given wind velocity, blowing for a sufficiently long time over a given distance, a certain wave spectrum develops which can be characterized by the higher and more conspicuous waves present.

During growth energy is transferred from the wind partly by normal pressures, that is by the excess pressure which the wind exerts on the windward side of the wave, and partly by tangential stress, that is by the drag exerted by the wind on the surface. The growth of the higher waves, which have been called the significant waves, can be examined quantitatively (Sverdrup and Munk, 1947) by an analysis of the energy transfer, using in the case of the wind stress the relationship between wind and stress which has been discussed. On certain assumptions it is found that the results can be represented by dimension- less ratios and that, by adjustment of one single numerical constant, good agreement is established between observed and computed values. In this connection the agreement can be interpreted as showing that nearly correct quantitative values

of the wind stress have been used, meaning that the examination of the growth of wind waves substantiates the conclusions as to the relationship between wind and stress.

When the waves leave the wind area and travel through regions of calm they will no longer be subjected to the effects of a wind stress, but will meet an air resistance by which they lose energy. The effect of the air resistance is highly selective in that the shorter waves are dissipated much more rapidly than the longer waves. Consequently the shorter waves are soon eliminated from the wave spectrum and only the longer ones continue over large distances as swell, which with increasing distance from the storm area becomes more regular and smooth in appearance. The further the swell travels the longer are the highest remaining waves, so that apparently the length and period of the swell increases with increasing distance from the storm. This increase, however, does not imply that the period of individual oscillation increases, but it is brought about by a selective dissipation of the numerous oscillations that emerge from the storm area.

4. The Pure Wind Current

Besides contributing to the growth of waves the wind stress also develops and maintains temporary and permanent currents. In the latter case the wind stress maintains a distribution of mass which can exist only in the presence of currents.

The character of the temporary or pure wind current was first recognized by Fridtjof Nansen, who during the drift of the *Fram* across the Polar Sea in 1893–96 observed that the ice always drifted to the right of the wind direction. Nansen ascribed this feature to the combined effects of the stress exerted by the wind, the frictional stresses in the water and the Coriolis force that arises because of the rotation of the earth. Ekman (1902) developed these concepts analytically and found that under certain simplifying assumptions the surface current is directed 45° from the wind, to the right in the Northern, to the left in the Southern Hemisphere. With increasing depth the current turns linearly to the right, and its velocity decreases

exponentially so that the end-points of the vectors representing the current at different depths lie on a logarithmic spiral, commonly referred to as the "Ekman spiral." The total mass transport by the pure wind current is directed at right angles to the wind, regardless of details as to the velocities. These conclusions have been confirmed qualitatively, but as yet there are not available quantitative results that confirm our knowledge of the wind stress.

5. Permanent Currents

In several special cases it has been shown qualitatively that the transport of the light surface layer by the wind must lead to a redistribution of mass, which can remain permanent only in the presence of a permanent current running more or less in the direction of the wind. Therefore, it is argued that the wind maintains the permanent currents of the oceans, but so far quantitative relationships have not been established. The question before us now is whether our better knowledge of the wind stress and its effect can be used to develop quantitative laws.

For this purpose seasonal and annual charts of the wind stress have been prepared at the Scripps Institution of Oceanography of the University of California at La Jolla, California. The annual chart for the North Pacific (fig. 2) shows quite simple features. To the north of 35° N., where the westerlies prevail, the stress is directed towards the east, whereas within the trade-wind belt, between about 5° N. and 25° N., the stress is directed towards the south-west. The high-pressure area off the North American west coast appears as a point of divergence and the equatorial front in latitudes 5° N. to 10° N. as a line of convergence.

A comparison between this chart of the wind stress and a chart of the mass transport by the currents of the North Pacific (fig. 3), which was prepared several years ago (Sverdrup *et al.*, 1942), reveals both similarities and striking discrepancies. The directions of the currents in the region to the north of 35° N. and in the trade-wind region between 10° and 20° N. coincide more or less with the directions of the stress in these latitudes,

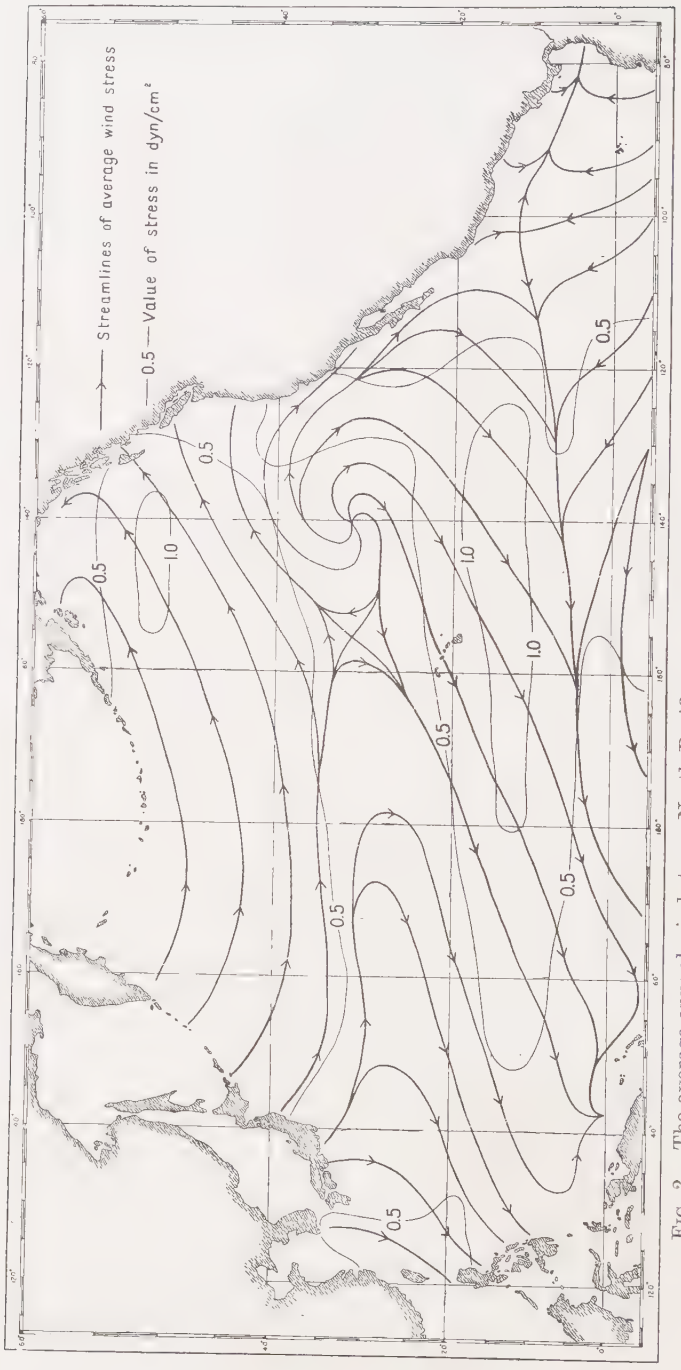

FIG. 2.—The average annual wind stress, North Pacific, represented by streamlines and iso-lines in dynes/cm.^{2}

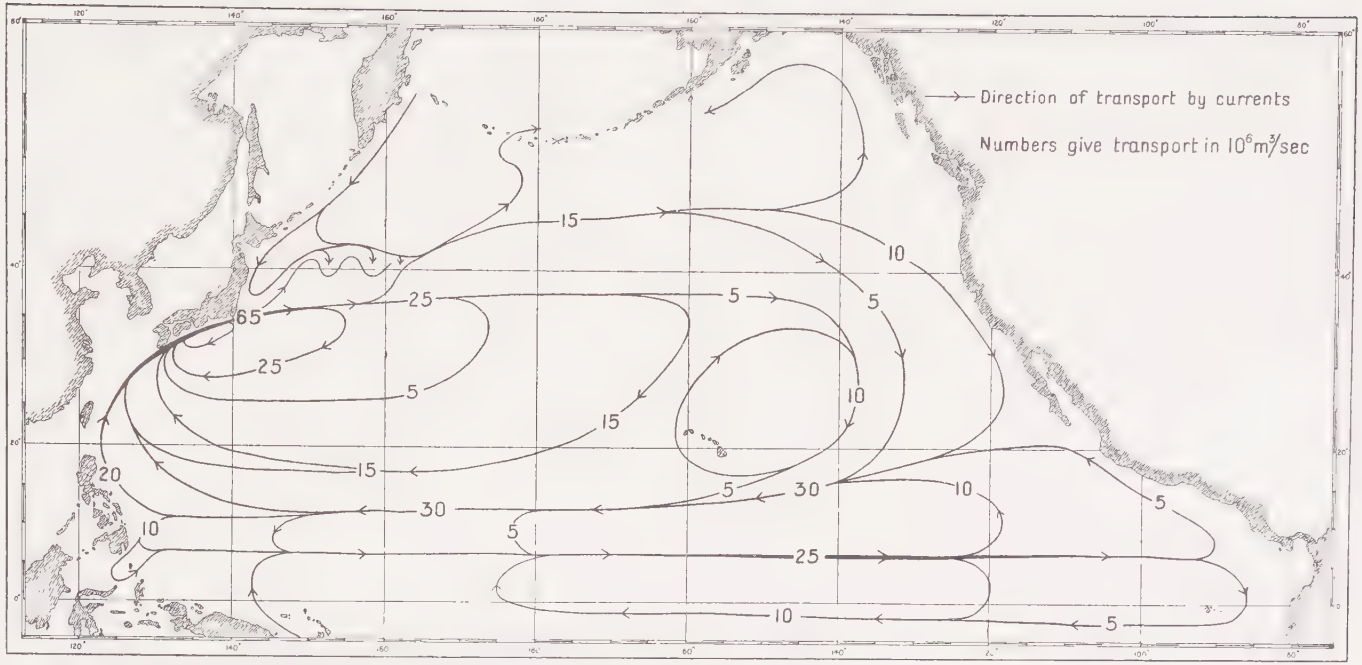

FIG. 3.—Transport of water by the permanent currents of the North Pacific. The lines with arrows indicate the approximate direction of the transport above 1500 metres, and the inserted numbers give the transported volumes in millions of cubic metres per second. (Modified from Sverdrup *et al.*, 1942.)

and the location of the anticyclonic circulation to the north-west of the islands of Hawaii agrees reasonably well with the location of the divergence-point in the field of stress. The most striking discrepancies are that the currents are concentrated in the western part of the ocean where the Kuroshio dominates, and that in latitude 5° N. to 10° N. a strong current, the Equatorial Counter Current, flows directly against the prevailing stress. It will be shown that both these features can be accounted for, the former qualitatively, the latter nearly quantitatively.

The crowding of the streamlines along the western boundaries results, according to Stommel (1948), from the effects of the boundaries and the variation of the Coriolis force with latitude. Stommel has selected a model which can be dealt with analytically, but does not correspond to actual conditions. The essential assumptions as to the wind stress are that the stress is constant in an east-west direction, but varies north-south as a cosine function (fig. 4). The water is supposed to be of constant density and of small depth; a frictional force is introduced, acting against the current, and a Coriolis force is taken into consideration that increases linearly to the north. Stommel emphasizes the artificial nature of the theoretical model, but thinks his results suggestive. He finds that without the Coriolis force, or with a constant Coriolis force, the streamlines of the flow that is maintained by the stress are symmetrical, but with a Coriolis force that increases to the north the symmetry disappears and the streamlines become intensely crowded along the western boundary, as shown in fig. 4.

There is a striking similarity between fig. 4 and the western area in figs. 2 and 3. In order to present it more clearly, fig. 5 has been prepared, in which the streamlines of the wind stress acting on the western North Pacific and the streamlines of the total transport by the ocean currents have been entered on the same chart. The total transport between two of the latter streamlines amounts to 20 million cubic metres per second. The presentation corresponds to Stommel's, but the numerical values in the two graphs are not comparable because of Stommel's assumptions. The agreement between the general features is, however, so good that it seems correct to conclude that the currents of the western North Pacific are maintained by the

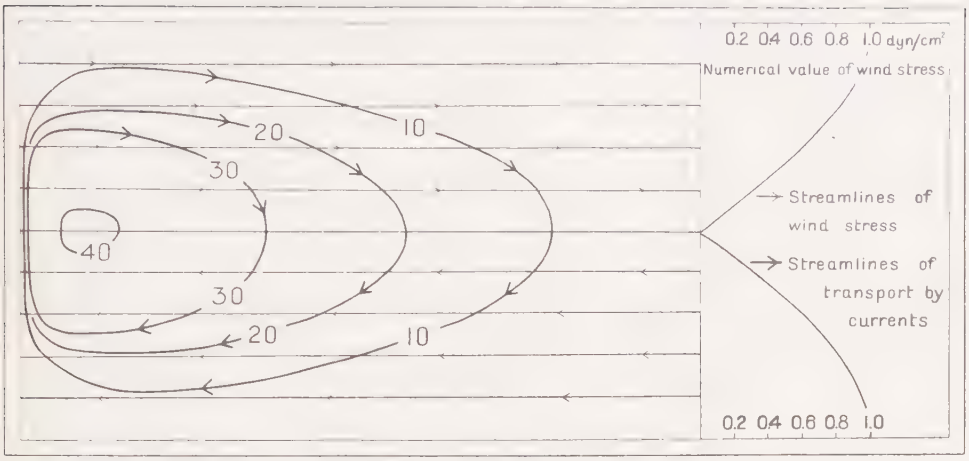

FIG. 4.—Schematic representation of the circulation in a shallow rectangular basin in the Northern Hemisphere, according to Stommel (1948).

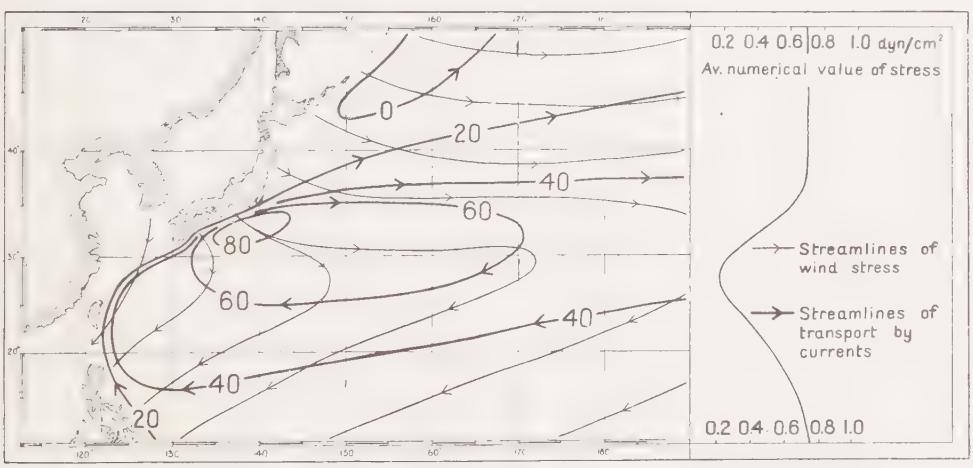

FIG. 5.—Wind stress and streamlines of transport by ocean currents, western North Pacific. Between two streamlines the transport is 20 million cubic metres per second.

wind stress and that the crowding along the western boundary is due to the effects of the boundary and the variable Coriolis force, but the quantitative relationship has yet to be established.

Turning next to the Equatorial Counter Current, Stockmann (1946) has shown that a counter current must be present because of the north-south variation in the wind stress. His results are qualitative because of the nature of his assumptions, and because he failed to take into account the variation with latitude of the Coriolis force. Doing this, and dropping certain artificial assumptions, it is possible to compute the distribution of mass in the eastern equatorial Pacific from the wind stress alone, and to compare this to the observed distribution of mass.

The distribution of mass can be described by a function P which represents the integrated pressure p between the surface and a depth d:

$$\mathrm{P} = \int_0^d p dz. \tag{4}$$

The numerical value of this function can readily be found at each oceanographic station with serial observations of temperature and salinity.

Assuming no motion at and below the depth d and neglecting accelerations and lateral frictional stresses the derivatives of P can be expressed as functions of the wind stress, represented by the vector τ, and the latitude, ϕ (Sverdrup, 1947 *b*):

$$\frac{\partial \mathrm{P}}{\partial x} = \int_0^d \frac{\partial p}{\partial x} dz = \mathrm{R}\ \mathrm{curl}\ \tau \tan \phi + \tau_x \tag{5a}$$

$$\frac{\partial \mathrm{P}}{\partial y} = \int_0^d \frac{\partial p}{\partial y} dz = \mathrm{R} \int_{x_1}^{x_2} \frac{\partial}{\partial y} (\mathrm{curl}\ \tau \tan \phi) dx - \int_{x_1}^{x_2} \mathrm{curl}\ \tau dx - \mathrm{R}(\mathrm{curl}\ \tau \tan \phi)_{x=x_1} \cot \alpha + \tau_y. \tag{5b}$$

Here R is the radius of the earth. The co-ordinate system has been placed with the x-axis along the Equator, positive to the east. At $x = x_1$ a vertical boundary is introduced, forming an angle α with the positive x-axis. The derivatives defined by equations (5*a*) and (5*b*) can be computed if the field of the wind stress is known and, except for an arbitrary constant, the function P can be obtained by numerical integration.

From the eastern equatorial Pacific there are available several oceanographic observations off the American west coast, taken by the *Carnegie* in October–November 1928 (Fleming, 1945) and by the *Bushnell* in March 1939 (Sverdrup and staff, 1943). In longitudes 135 to 150 W.Gr. there is a north-south line of stations which were occupied by the *Carnegie* in October–November 1929 (Fleming, 1945). From these oceanographic observations a chart of the P-function was derived by integration between 0 and 1000 m. (fig. 6). The wind stress was computed from the climatological data in the Pilot Charts for October and November, and on this basis a second representation of the P-function was found (fig. 7). The arbitrary constant involved was selected to bring the numerical values in figs. 6 and 7 in agreement, but this selection has no bearing on the shape or spacing of the P-lines in fig. 7.

There exists a great similarity between the two charts. Between the coast and 120° W.Gr. the integrated pressure is nearly constant, except that the oceanographic observations indicate a "high" in about 13° N., 110° W.Gr. which may be produced by local winds. To the west of 120° W. both charts show strikingly similar features, except that some discrepancy occurs in the immediate vicinity of the Equator, perhaps because lateral friction may be of importance where the Coriolis force vanishes. The Equatorial Counter Current flows towards the east between the dashed lines marked "Trough" and "Ridge." The locations of these lines as derived from the wind observations (fig. 7) agrees remarkably well with the locations derived from the observations of temperature and salinity (fig. 6), particularly when one considers that the latter represent results obtained from a few scattered oceanographic observations, whereas the former are based on climatological data. This agreement supports the contention that the counter current is maintained by the prevailing winds. Furthermore, the general agreement supports the assumption that the horizontal pressure gradients vanish at and below the depth, d, meaning that the effect of the wind stress is limited to the upper layers and that within the region under discussion no motion is produced in the deeper layers.

The simple analysis by which the results in fig. 7 have

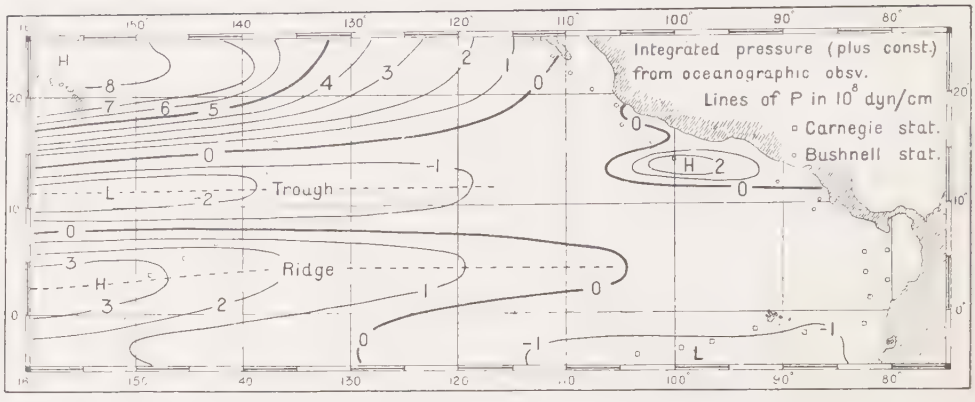

FIG. 6.—Integrated distribution of pressure between the sea surface and a depth of 1000 m., eastern equatorial Pacific, derived from oceanographic observations mainly in October–November 1928 and 1929.

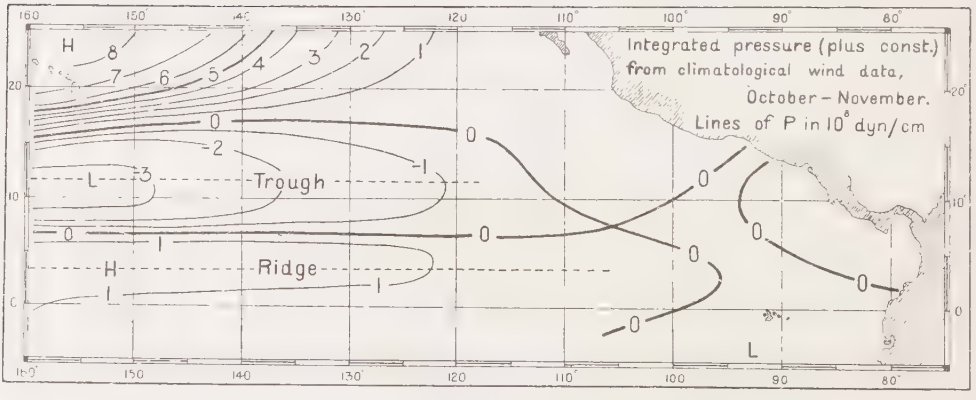

FIG. 7.—Integrated distribution of pressure between the sea surface and a depth of 1000 m., eastern equatorial Pacific, calculated from climatological charts of winds in October–November.

been derived cannot be applied to conditions along the western boundary of the ocean, because there the boundary condition cannot be satisfied without taking field accelerations or lateral friction into account. There is every reason to believe that one would obtain an equally good agreement if this could be accomplished.

6. Conclusions

The results in the preceding section are encouraging. One may hope to show quantitatively that all permanent ocean currents are maintained by the average wind stress, and if this can be achieved one may be able to tackle the more difficult problems of seasonal fluctuations and changes in the ocean currents related to changes in the winds. Ultimately one has to go even further, because so far the problem of oceanographic circulation has been dealt with as a strictly hydrodynamic one, whereas in the last analysis it is necessary to consider also the effects of heating and cooling towards altering the density of the surface layer and towards producing small- and large-scale vertical convection currents. In this discussion I have intentionally suppressed the importance of the thermal processes because I have wanted to demonstrate not only the obvious effect of the winds towards producing waves, but also the far more complicated wind effects by which the permanent currents of the oceans are maintained.

I hope that my examples have also demonstrated the value of the theoretical approach to problems in oceanography. It is hardly necessary to stress this point to the present audience, but I am mentioning it in order to emphasize the need for thorough training in the fields of the geophysical sciences. It is too often stated that advance in these sciences depends upon the accumulation of more and more facts, but all history tells us that every major step ahead is related to, and accomplished by, new and sound interpretation of facts. For this interpretation the theoretical tools are needed, and it is our responsibility to give the new students these tools. Our Association can contribute to some extent, for example by assisting in providing bibliographies, but the training of oceanographers is essentially

a function of individual members of our organization, a function to which particular attention should be paid during this period of rapidly expanding activity in the field of physical oceanography.

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General Resolutions

Adopted by the General Assembly of the Union

on 28th August 1948, on the recommendation of the Association

1. The International Union of Geodesy and Geophysics supports the application of the Joint International Commission on Oceanography to UNESCO that financial assistance be given by UNESCO to the Oceanographic Institute at Monaco, in order to ensure the continued activity of this Institute, which has been of outstanding importance to physical oceanography.

2. The International Union of Geodesy and Geophysics considers that to provide data for a satisfactory study of mean sea-level and its variations on the Indo-Burma-Malaya-Siamese waters and also for detailed studies of many other geophysical problems, such as the secular subsidence or elevation of land, the present number of active tide-gauge stations on the Indo-Burma Coast is far from adequate, and strongly recommends to the Governments concerned the establishment of a number of additional permanent tide-gauge Observatories on their coasts as soon as practicable.

Administrative Reports

Report of the Secretary for the Period 1939-48

In December 1945 Professor Helland-Hansen was elected President of the International Union and in consequence resigned the Presidency of the Association. The Executive Committee of the Association then elected Professor Sverdrup as President of the Association, and he has served in this capacity since March 1946.

At the meeting of the Executive Committee of the Union in December 1945 it was deemed desirable that each Association should elect a Deputy Secretary. In January 1947 the Executive Committee of the Association of Physical Oceanography elected Professor Mosby as Deputy Secretary of this Association, and he has since acted in this capacity.

Since the end of the War the Executive Committee has reorganised several of the scientific committees of the Association.

The chairmanship of the Committee on Mean Sea-level became vacant through the death of Professor Witting, and his place has been taken by Admiral Nares.

The secretaryship of the Committee on Chemical Methods and Units became vacant through the death of Professor Jacobsen. Professor Thompson has been made chairman in place of Professor Helland-Hansen and he also takes the duties of secretary.

The chairmanship of the Committee on the Major Divisions of the Ocean-bottom became vacant on the resignation of Dr. Wayland Vaughan. On the nomination of Dr. Wayland Vaughan, Professor Kuenen was elected to succeed him.

The Executive Committee has also established two new scientific committees.

One of these is on Oceanographical Observations from the

Atlantic Weather Ships; its chairman is Dr. Fleming and its secretary Professor Mosby.

The other is on the Preparation of a Technical Handbook on Physical Oceanography, and its chairman is Professor Sverdrup.

The Executive Committee has agreed that the Association assume responsibility for the future preparation and distribution of standard sea-water. The work will still be carried out in the Danish Hydrographical Laboratory, but financial arrangements will be made by the Association.

At the request of the President, the Secretary enquired of National Committees as to the demand for bathythermographs.

Since the General Assembly at Washington in 1939 the following publications have been issued:

Procès-Verbaux

No. 3. General Assembly at Washington, September 1939 (1940).

Publications Scientifiques

No. 6. Bibliography on Tides and certain kindred matters (Fifth instalment) (1939).

No. 7. J. P. Jacobsen and Martin Knudsen: Urnormal 1937 or Primary Standard Sea-water 1937 (1940).

No. 8. Report of the Committee on the Criteria and Nomenclature of the Major Divisions of the Ocean-bottom (1940).

No. 9. Report of the Committee on Chemical Methods and Units (1948).

The above publications have been distributed as far as circumstances would allow. Up to 1941 the Secretary addressed copies to libraries and individuals in the member-countries, but since the War he has sent one batch to each country, leaving the detailed distribution to be arranged by the National Committee of each country.

In 1946 the International Council of Scientific Unions established a Joint Committee of the Union of Geodesy and

Geophysics and of the Union of Biological Sciences on the subject of Oceanography. The first members were nominated by the two Unions and included the President and Secretary of the Association of Physical Oceanography. The Chairman of the Joint Committee is Professor H. Boschma of Leiden and the Secretary is Lieutenant-Colonel R. B. Seymour Sewell of Cambridge.

(The above Report was unanimously adopted by the General Assembly of the Association on 25th August 1948.)

Financial Report for Period 1939-47

A summary statement of the Income and Expenditure for the period 1st January 1939 to 31st December 1947 and the Balance Sheet for 31st December 1947 are given in the accompanying tables.

The expenditure on secretarial assistance incurred during 1939 and 1940 included payment for much scientific work on the preparation of *Publication Scientifique No. 5 on Mean Sea-level* and also on the *Bibliography on Tides*. At that time the Secretary could not communicate with the committees dealing with these matters so as to obtain their sanction for the expenditure and it is therefore entered as expenses of the Bureau.

The investment of £2000 in British National War Bonds has increased the income of the Association.

ACCOUNTS FOR THE PERIOD 1st JANUARY 1939 TO 31st DECEMBER 1947.

Income.

	1939. £ s. d.	1940. £ s. d.	1941–47. £ s. d.
Allocations from Union	602 0 0	229 17 4	..
Interest on Investment (net)	..	..	108 16 4
Sale of publications	0 4 6	..	1 15 0
Bank Interest	21 13 3	17 9 2	59 0 0
	623 17 9	247 6 6	169 11 4

Expenditure.

	1939. £ s. d.	1940. £ s. d.	1941–47. £ s. d.
Work on Mean Sea-level	..	..	26 0 0
Chemical Units Committee	200 0 0	..	..
Gulf Stream Committee	200 0 0	..	..
Publications:			
Publication Scientifique No. 5	..	542 4 3	..
Publication Scientifique No. 6	..	11 6 0	..
Publication Scientifique No. 7	..	41 11 6	..
Publication Scientifique No. 8	..	210 2 0	..
Procès-Verbaux No. 3	..	199 7 6	..
Mean Sea-level, 1937	29 17 6	..	..
Mean Sea-level, 1938	..	25 18 0	..
Meetings, Travel, etc.	87 15 3	..	6 18 10
Bureau:			
Secretarial Assistance	95 16 0	112 8 0	0 3 3
Printing	4 6 6	22 4 6	..
Stationery and Supplies	15 9 1	3 1 9	5 14 8
Postage and Carriage	9 3 10	22 8 8	12 17 8
Insurance	..	..	30 0 0
Miscellaneous	3 14 5	7 15 10	2 2 0
	646 2 7	1198 8 0	83 16 5
	£22 4 10 Deficit.	£951 1 6 Deficit.	£85 14 11 Credit.

BALANCE SHEET AT 31st DECEMBER 1947.

Funds and Liabilities.

	£ s. d.	£ s. d.
Accumulated funds at 1st January 1939 .	..	3934 17 8
Deduct revenue deficit for:		
Year to 31st December 1939 . . .	22 4 10	..
,, ,, ,, 1940 . . .	951 1 6	..
Period 1.1.1941 to 31.12.1947 (surplus) .	85 14 11	
		887 11 5
		3047 6 3

Assets.

	£ s. d.
£2000 2½% National War Bonds, 1951–53	2000 0 0
Cash at Martins Bank Ltd., Liverpool	1046 19 6
Cash in hands of Secretary of the Association . . .	0 6 9
	3047 6 3

(*Signed*) J. PROUDMAN (*Secretary*).

I have examined the accounts of the Association of Physical Oceanography for the nine years ended 31st December 1947 and I hereby certify that the said accounts are in order.

(*Signed*) R. Lewin (*Incorporated Accountant*).

Liverpool, 23*rd January* 1948.

(The above Report was unanimously adopted by the General Assembly of the Association on 25th August 1948.)

Statutes
Adopted by the General Assembly at Oslo, August 1948

I. *Objects, Composition and Membership of the Association*

1. The International Association of Physical Oceanography is a constituent of the International Union of Geodesy and Geophysics. The Association is subject to those articles of the Statutes and By-laws of the Union which apply to Associations, and also to these Statutes.

2. The Objects of the Association are:

(*a*) To promote the study of scientific problems relating to the Oceans, chiefly in so far as such study may be carried out by the aid of mathematics, physics and chemistry;

(*b*) To initiate, facilitate and co-ordinate research into, and investigation of, those problems of physical oceanography which require international co-operation;

(*c*) To provide for discussion, comparison and publication.

3. Those countries which adhere to the Union are Members of the Association.

By resolution of a General Assembly of the Association, other international organisations which are concerned with the study of physical oceanography may be admitted to Membership, with the status of guests.

II. *Administration*

4. The Authority of the Association shall be vested in the countries adhering to the Union, and exercised collectively by their delegates meeting in General Assembly of the Association.

5. There shall be an Ordinary General Assembly of the Association each time that there is an Ordinary General Assembly of the Union. With the concurrence of the Executive Committee of the Union, there may be an Extraordinary General Assembly of the Association at other times.

6. The General Assembly of the Association shall elect the President, the two Vice-Presidents, the Secretary and the Deputy-Secretary of the Association.

7. The Bureau of the Association shall consist of the President and Secretary. Its duties shall be to conduct the affairs of the Association in accordance with the decisions of the foregoing General Assemblies of the Association. It shall prepare the Agenda for General Assemblies.

8. The General Assembly of the Association shall elect, from countries which adhere to the Union, four persons who, together with the President, Vice-Presidents, Secretary and Deputy-Secretary, shall constitute the Executive Committee of the Association.

III. *Voting Power*

9. On scientific matters, each delegate present shall have one vote.

10. In questions of administration or of mixed administrative and scientific character not involving questions of finance, voting shall be by countries, each country having one vote with the provision that its subscription shall have been paid up to the end of the year preceding the voting.

11. In questions involving finance, voting shall be by countries, with the same provision as for administrative questions. The number of votes for each country shall be one greater than the number of its category of membership of the Union.

12. In case of doubt as to which class a question belongs, and in all cases of equality of votes, the chairman shall decide.

13. No delegate shall represent more than two countries. An adhering country not represented by a delegate may forward by post its vote on any specific question of an agenda.

14. Guests will not vote.

IV. *General*

15. These Statutes shall be changed only by a majority of two-thirds of the votes cast at a General Assembly by delegates or by post.

16. The Association may make By-laws which may be changed by a simple majority of the votes cast at a General Assembly by the delegates or by post.

17. This English text shall be the authoritative text of the Statutes of the Association.

By-laws

Adopted by the General Assembly at Oslo, August 1948

I. *Membership of the Association*

1. It is recommended that each adhering country shall form a National Sub-Committee for Physical Oceanography, to which correspondence may be addressed.

2. Each adhering country and each international member may contribute to the Agenda of General Assemblies of the Association.

II. *Administration*

3. (*a*) The President and Vice-Presidents of the Association shall be elected for one period, the term "period" being taken to mean the interval between the ends of two successive ordinary General Assemblies. They may be re-elected, but not for more than one additional period.

(*b*) The Secretary and Deputy-Secretary shall be elected for two periods, and may be re-elected for subsequent single periods.

4. The Secretary shall manage the routine business, conduct the correspondence, preserve the records, and arrange the preliminaries of General Assemblies in collaboration with the General Secretary of the Union.

5. Of the four persons referred to in Article 8 of the Statutes, two shall retire after each ordinary General Assembly and they shall not be eligible for re-election until after the expiration of one period. Each retiring member shall have served at least as long as each non-retiring member.

6. The Executive Committee shall:

(*a*) Advise the Bureau whether an Extraordinary General Assembly is necessary.

(*b*) Fill any vacancy which may occur among the officers of the Association between General Assemblies. Such appointments shall be subject to the subsequent approval of the next General Assembly. Tenure of office for part of a period shall not be counted as a period for the purpose of these By-laws.

(*c*) Consider matters of general administration and finance, and report thereon to the General Assembly.

(*d*) Make recommendations on matters of policy.

(*e*) Frame the budget for the ensuing period and report to the General Assembly of the Association and to the General Secretary of the Union.

(*f*) Advise upon the distribution of funds.

(*g*) Consider proposals for changes in the Statutes and By-laws, and report thereon to the General Assembly.

7. Officers designated by these By-laws for special duties or for special committees may appoint substitutes in their stead. Notice of the intention to do so must be sent in writing to the President or Secretary. No substitute shall represent more than one officer.

8. Decisions and actions of the Officers and Committees of the Association, taken during and between General Assemblies, shall be subject to the sanction of the General Assembly.

9. Proposals for the Agenda of a General Assembly shall reach the Secretary six months before the General Assembly. The Secretary shall send the Agenda to adhering countries, through the National Sub-Committees where such exist, at least four months before the General Assembly. No question which has not been placed on the Agenda shall be discussed

unless a proposal to that effect be approved by two-thirds of the votes of the countries represented at the Assembly.

III. *Finance*

10. The President and Secretary shall individually have power to sign documents on behalf of the Association.

11. The Secretary shall receive the allocations of funds from the Union, and administer the funds of the Association. At the end of the calendar year preceding a General Assembly he shall prepare and send to the General Secretary of the Union the Accounts of the Association.

12. Each Account shall be audited by a qualified accountant.

13. Travelling expenses may be paid by the Secretary, but only (*a*) in connection with meetings on specific Association business, and (*b*) when those concerned represent the Association and not adhering countries or other organisations, and (*c*) in cases where those concerned cannot draw proper allocations from their own national sources. Such payments may cover travelling costs and a reasonable contribution to other expenses while attending such meetings.

Officers and Executive Committee

Appointed by General Assembly at Oslo, August 1948

President:	Professor H. U. Sverdrup, Norsk Polarinstitutt, Oslo, Norway.
Vice-Presidents:	(1) Professor J. Proudman, The University, Liverpool, England.
	(2) Dr. C. O'D. Iselin, Woods Hole Oceanographic Institution, Mass., U.S.A.
Secretary:	Professor H. Mosby, Geofysisk Institutt, Bergen, Norway.
Deputy Secretary:	Dr. R. H. Fleming, Hydrographic Office, U.S. Navy, Washington, D.C., U.S.A.

Members:

Dr. J. N. Carruthers, Great Britain.
Professor H. Pettersson, Sweden.
Captain J. Rouch, France.
Vice-Admiral J. W. Termijtelen, Netherlands.

Scientific Committees

Appointed by General Assembly at Oslo, August 1948

Committee on Tides

Chairman:	H. A. Marmer.
Secretary:	J. Proudman.
Members:	J. E. Fjeldstad, A. Gougenheim, W. Horn, N. Menendez, M. Tenani.

Committee on Mean Sea-level and its Variations

Chairman: J. D. NARES.
Secretary: R. H. CORKAN.

Committee on Nomenclature of Ocean-Bottom Features

Chairman: J. D. H. WISEMAN.
Secretary: J. D. NARES.
Members: K. O. Emery, H. H. Hess, Ph. H. Kuenen, H. Pettersson.

Committee on Oceanographical Observations from Atlantic Weather Ships

Chairman: R. H. FLEMING.
Secretary: H. MOSBY.
Members: J. le Gall, H. Keyser, M. Knudsen, J. R. Lumby, F. S. Russell.

Committee on Preparation of Technical Handbook on Physical Oceanography

Chairman: H. U. SVERDRUP.
Members: J. N. Carruthers, G. E. R. Deacon, E. C. La Fond, H. Mosby, N. W. Rakestraw.

Committee on Questions concerning Preparation of a Bibliography

Chairman: H. U. SVERDRUP.
Secretary: P. GROEN.
Members: H. L. G. Bencker, J. N. Carruthers, L. Fage, J. R. Lumby, R. B. Montgomery, R. Revelle, J. T. Ruud, F. Vercelli.

Reports of Scientific Committees

D 1

Report of Committee on Tides

By

J. PROUDMAN

Secretary

Since the Washington Assembly much work has been done on the preparation of the "Bibliography on Tides," chiefly in the filling of the gaps which exist in the five published instalments. The "Bibliography" is now in card form, arranged in a single chronological sequence from the beginnings of published research up to the end of the year 1939. The subject-matter is divided into sixteen divisions, and the contents of each publication recorded are indicated by one or more of sixteen letters. It is proposed to make an author index.

Though the "Bibliography" can now only be regarded as of value for studies of the history of knowledge of the tides, yet it is proposed to publish it as one book according to the decision of the Association taken at Edinburgh in 1936.

D 2

Report of Committee on Mean Sea-Level and its Variations

By

J. PROUDMAN

Secretary

The chairmanship of the Committee rendered vacant by the death of Professor Witting has been filled by the appointment of Vice-Admiral Nares, President of the Directing Committee of the International Hydrographic Bureau. This is specially appropriate as the greater part of the work of collecting data on the observed heights of sea-level is carried out by the International Hydrographic Bureau.

Very little of this collecting could be done during the war years, but it has been carried on actively during 1947 and 1948. It is intended that this data shall be tabulated in the same form as in *Publication Scientifique No.* 5 and then published. The next publication will cover a number of years beginning with 1937, thus incorporating the matter of the two pamphlets for 1937 and 1938, which were published separately in 1939 and 1940.

D 4

Report of Temporary Committee to consider the question of Reappointment of the Committee on Criteria and Nomenclature for the Major Divisions of the Ocean Bottom

By

J. B. TAIT
Chairman

Need.—To foster uniformity in the nomenclature of topographical features of the ocean bottom.

Function.—To endeavour to establish, in co-operation with the chart-making authorities, mechanisms for international agreement on the nomenclature of submarine topographical features.

Name.—Committee on Nomenclature of Ocean Bottom Features.

Composition.—Chairman, Secretary, four designated members and others co-opted at the discretion of the Committee.

Nominations:

Chairman: Dr. J. D. H. Wiseman.

Secretary: Vice-Admiral J. D. Nares.

Members: Dr. H. H. Hess, Prof. Ph. H. Kuenen, Prof. Hans Pettersson.

Terms of Reference.—In carrying out its function the Committee should endeavour to co-ordinate the views of submarine geologists, hydrographers, and others concerned in the naming of submarine topographical features.

Recommendation.—The Sub-Committee also discussed the question of other oceanographical nomenclature, *e.g.* of currents, and recommends that the Association considers the desirability of appointing a parallel Committee for such problems.

D 5

Report of Committee on Oceanographical Observations from Atlantic Weather-ships

By

R. H. FLEMING
Chairman

I. It is generally recognized that the Atlantic Weather-ship Programme offers a new and unique opportunity for collecting long systematic series of physical and biological observations at fixed points and over repeated routes in the open ocean.

Such data collected over long periods could form a basis for "climatic" studies and would provide a means for preparing synoptic charts. The Committee feels, however, that it is premature to recommend a formal programme to be undertaken by all countries participating in the Weather-ship Programme.

II. The following factors are believed to be important in planning for any such programme:

(1) The number of stations (and vessels) planned to be operated by the several countries varies between a fraction of a vessel to approximately twenty-five.

(2) The actual number of stations in operation is variable and the size and duration of the programme is uncertain.

(3) Personnel and equipment are scarce in all countries and hence the exploitation of the weather-ships will, of necessity, be in competition with other oceanographic programmes.

III. In view of the above it is recommended that—

(1) Each country be encouraged to undertake systematic, physical, chemical, geological and biological observations as their individual facilities and personnel permit.

(2) That the Committee be continued and that its functions shall include:

(*a*) liaison with the national committees;

(*b*) gradual development of a uniform programme;

(*c*) arrangements for the exchange and for publication of data.

D 6

Report of Committee on Technical Handbook

By

H. U. SVERDRUP
Chairman

On the suggestion of H. U. Sverdrup, the Executive Committee of the Association agreed to establish a Committee for the Preparation of a Technical Handbook in Physical Oceanography. Sverdrup should head this Committee. The decision of the Executive Committee was communicated to Sverdrup by the Secretary, Professor J. Proudman, in a letter of 25th June 1947.

After discussion with several colleagues Sverdrup prepared an outline of the Handbook, which he proposed should be prepared in five sections. In letters of 24th October 1947 Sverdrup asked the following persons to serve on the Committee and to accept the responsibility for the preparation of the different sections:

Section A. Ship Facilities: G. E. R. Deacon.

Section B. Work at Sea: H. Mosby.

Section C. Processing at Sea: N. W. Rakestraw.

Section D. Processing Ashore: E. C. La Fond.

Section E. Glossary: J. N. Carruthers.

All the above agreed to serve.

In writing to the different persons Sverdrup suggested that they, in turn, should consult other colleagues, so that,

in fact, the Committee will be composed of a number of sub-committees for each section, the members of the sub-committees being selected by the person responsible for that section.

Abstracts of Communications

F 1

Limits of Oceans and Seas

By

J. D. NARES

International Hydrographic Bureau

A short account will be given of early studies of limits seemed fit to apply to the oceans and seas. The reasons will be explained which urged the International Hydrographic Bureau to prepare *Special Publication No.* 23, "Limits of Oceans and Seas," together with the principal object of this publication, namely to unify the different publications issued by Hydrographic Offices, it not being contended that all necessities of oceanography and allied sciences should be complied with.

Short notes will be given of discussions which took place on this subject during the various International Hydrographic Conferences, 1919 to 1947, which resulted in the issue of the first two editions of *Special Publication No.* 23, dated August 1928 and July 1937 respectively, and of the work now in hand of preparing a third edition, a draft of which, accompanied by three charts showing the proposed limits, will be presented for discussion by the Association.

F 2

Extension of World Network of Tidal and Tidal Stream Stations

By

J. D. NARES
International Hydrographic Bureau

A short account will be presented of the action taken by the International Hydrographic Bureau to comply with the recommendation of the Vth International Hydrographic Conference, 1947, that increased attention be given to the need of obtaining supplementary observations of tides and tidal streams in many areas which are not now adequately examined.

A chartlet of the world showing the areas where information is most deficient at this time will be presented.

F 3

Dimensions of Wind-generated Waves

By

J. Th. THIJSSE
Technical University of Delft

The diagram constructed by Sverdrup and Munk * shows the generation of surface waves by wind blowing over water of infinite depth. In the Netherlands it is often necessary to predict the dimensions of waves which arise in shallow water.

Near the windward shore the wave-length is small, so that the orbital movement does not extend as far as the bottom and the Sverdrup diagram may be used.

As the waves grow, the velocity near the bottom will gradually become great enough to cause a considerable loss of energy by friction.

After a certain fetch has been covered, a state of equilibrium is reached in which this loss of energy together with the other losses counterbalances the energy brought into the wave system by the wind.

This state of affairs may be shown in an addition to the above-mentioned diagram. Like the fetch F, the length L, and the height H of the wave, the depth of the water D is made dimensionless by dividing by double the "velocity-head" of the wind, $w^2 : g$. There appears a series of lines for $H : (w^2 : g)$, one for each relative depth $D : (w^2 : g)$. Another series is valid for $L : (w^2 : g)$ or for the relative radius of the "generating circle" $r : (w^2 : g) = L : 2\pi(w^2 : g)$. The latter may be given in a diagram for the transition from deep-water waves to shallow-water waves. No attempt has yet been made to explain the phenomena

* H. U. Sverdrup and W. H. Munk: "Empirical and Theoretical Relations between Wind, Sea and Swell," Trans. Amer. Geophys. Union, Vol. 27, pp. 823–827, 1946.

theoretically: the diagram is merely based on the results of observations which the Hydraulic Laboratory at Delft has at its disposal. Some of these observations have been made in the open air, others in a flume in the laboratory. This flume has a length of 50 metres, its depth is about 0·3 m.; the wind can be adjusted to any velocity up to 17 metres per second.

As the velocity of the wind increases with the height, it is necessary to define w the velocity of the air at a given height z. For this height $z=(w^2:g):5$ has been chosen.

If the wind measured at this level is used in the diagram, it is necessary to modify the Sverdrup line slightly in order to cover the dimensions observed. These dimensions are greater than those corresponding to the original Sverdrup lines, so that the lines in the new diagram are somewhat higher at low values of $F:(w^2:g)$. On the contrary, a few observations at high values of $F:(w^2:g)$ cause this part of the lines for infinite depth to be somewhat lower than that in the Sverdrup diagram.

The lines for limited depth join the one for the actual surface waves on the points for which D is about $3r$, viz. half the wave-length L. At this depth the influence of the bottom is being felt.

After the fetch has been reached at which the waves do not grow any more, the lines are horizontal. For very long waves the proportion between the velocity of propagation c and the speed of the wind w is equal to the square root of $D:(w^2:g)$. For deep water this proportion is the square root of $r:(w^2:g)$. In the transition, viz. the curved parts of the lines for limited depth, c does not follow directly from the diagram.

F 3

The Growth and Decay of Waves

By

G. E. R. DEACON

Oceanography Section, British Admiralty Research Laboratory

As soon as it was possible to examine continuous records of waves and to submit them to frequency analysis, it became evident that energy transferred from the wind to the waves was distributed over a range of wave-lengths, and that attempts to study the generation and propagation of waves must take full account of the composite character of the wave pattern and of the different capacities of the component wave trains for absorbing, retaining, and transferring energy.

Some progress has been made in the study of wave propagation. It has been shown that the mixture of waves generated in a storm comprises waves of all lengths up to a maximum which depends on the greatest wind strength, and by comparing the measured times at which the different wave-lengths begin and cease to arrive at a recording station, with the times (estimated from meteorological charts) at which they begin and cease to be generated in a distant storm area, it has been shown that the component wave trains behave independently of each other, and that each wave train advances across the ocean with a speed which (in relatively calm water) is within 5 per cent. of the theoretical group velocity appropriate to its period.

The problems of wave generation are more difficult, but since the basic requirement of a prediction of waves is the prediction of the wave spectrum, attempts are being made to find a formula for the energy associated with each individual wave-length in terms of the wind strength and duration. It is assumed that the energy absorbed by a particular wave train depends on the excess of the wind velocity over that of the waves,

and on the time during which the wind acts on the waves. It is also necessary to assume that the rate of growth depends in some way on the wave-length, since the shortest waves (moving much slower than the wind) are relatively small. There must also be a factor which is inversely proportional to the wind strength because the rate of growth of waves of a particular length appears to decrease when the wind exceeds some optimum strength. Finally an allowance has to be made for the decrease in the height of the waves after they have left the storm area, and the method used by Sverdrup appears the most satisfactory. He assumes that the process used by Jeffreys to explain the generation of waves is reversed when the waves travel faster than the wind, arguing there is an excess pressure on the forward side of the waves which tends to decrease them.

Empirical methods based on these assumptions have been used with fair success to predict the wave spectrum at any time on the Atlantic coast of the British Isles, and efforts are being made to obtain further experimental evidence and a suitable theoretical basis for the work.

F 4

The Applicability of Laplace's Differential Equations of the Tides

By

J. PROUDMAN

Department of Oceanography, University of Liverpool

The general differential equations for the tides, as given in Laplace's Mécanique Céleste, have been used by all the chief workers on the dynamical theory of the tides. But in 1933 V. Bjerknes, J. Bjerknes, H. Solberg and T. Bergeron, in their Physikalische Hydrodynamik, claimed that these equations are quite inadequate to deal with diurnal constituents of the tides, and this claim was maintained by Solberg in 1936 (Astrophys. Norveg.). In 1933 M. Brillouin and J. Coulomb pointed out that the equations did not appear to be valid for the semidiurnal tidal constituent K_2, whose period is half a sidereal day, in the Polar Sea (Inst. Mécan. Fluids, Paris).

Laplace neglected the vertical components of acceleration, both geostrophic and relative to the earth, and this makes the equations inadequate for a treatment of cellular oscillations in homogeneous water. Some of the features of cellular oscillations are possessed by the internal tides of stratified seas, but these can be dealt with on Laplace's principles. In 1939 (Astrophys. Norveg.) and 1943 (Geophys. Pub.) E. A. Hylleraas showed that the cellular oscillations with which Laplace's principles cannot deal do not occur in stratified water, and as the oceans are stratified this justifies the application of Laplace's equations to the actual oceans.

But most work on the dynamical theory of the tides has dealt with homogeneous water, and in 1941 I therefore made an investigation into the validity of Laplace's equations for such

oscillations of homogeneous water as are really like those of the actual tides (Proc. Roy. Soc., Vol. 179). My conclusions are that the equations are adequate for a treatment of all tidal constituents of the actual oceans. It is true that the equations are inadequate for the treatment of semidiurnal constituents near the North Pole and of long-period constituents near the Equator, but for an ocean in which such regions are only a small part the total effect of the inadequacy is small.

(The complete communication has been published in Internat. Hydrog. Rev., Nov. 1948.)

G 1

The Work carried out by the International Hydrographic Bureau

By

J. D. NARES
President of Directing Committee

These remarks will generally be confined to the progress of work carried out by the International Hydrographic Bureau since the General Assembly at Edinburgh in September 1936.

1. A short account will be given of the International Hydrographic Conferences held at Monaco in April 1937 and April–May 1947.

2. Work carried out:—

(*a*) The progress of the preparation of the 3rd edition of the General Bathymetric Chart of the Oceans.

(*b*) Work in connection with the "Committee on the Criteria and Nomenclature of the Major Divisions of the Ocean Bottom."

(*c*) Revision of I.H.B. Special Publication No. 23, "Limits of Oceans and Seas."

(*d*) Work in connection with the "Committee of Mean Sea Level" of the Association Internationale d'Océanographie Physique.

(*e*) The work of centralisation of Oceanic Soundings.

(*f*) Compilation of a Dictionary of Hydrographic Terms.

(*g*) Study of problems connected with Radio Aids to navigation, entailing the co-ordination of the Geographic Grids of the World.

(*h*) Progress of work in connection with I.H.B. Special Publication No. 26, "List of Harmonic Constants."

(*i*) Extension of World network of Tidal and Tidal Stream Stations.

(*j*) Other publications of the Bureau.

G 2

The Preparation of the Third Edition of the General Bathymetric Chart of the Oceans

By

J. D. NARES

(Extracts from a more detailed account prepared by Captain H. L. G. BENCKER, Secretary-General of the International Hydrographic Bureau)

The work of compiling the General Bathymetric Chart from its inception in 1899 to the present date will be described. The first two editions were produced under the direction of H.S.H. Prince Albert First of Monaco between the years 1903 and 1927 and a brief account of this work is given.

The advent of echo-sounding greatly increased the knowledge of the bathymetry of the oceans, and numerous international conferences recommended that these new soundings should be systematically centralised and incorporated in the General Bathymetric Chart. As Prince Albert had meanwhile, unfortunately, died, the International Hydrographic Conference, 1929, instructed the International Hydrographic Bureau to carry out this work. A description will be given of the preparation of a third edition of the General Bathymetric Chart, the plotting of which was commenced in 1931 and has been since continued, except during the years 1943–46 when the work was considerably interrupted owing to the War.

G 3

The Activities of the Oceanographic Section of the Koninklijk Nederlands Meteorologisch Instituut

During the War an Atlas of the Waters around Australia, containing mean monthly sea-surface temperature charts, monthly current charts, and maritime meteorological charts, was completed and is now in press. A similar Atlas of the Red Sea is in preparation.

Lack of oceanographic instruments and winches retards the taking up of oceanographic field-work, but observations on board the Netherlands Weather Ship in the future are planned.

A recording salinity meter which can be used from a moving ship has been developed and is being used for investigations in the Wadden Sea in combination with bathythermograph observations.

A theoretical investigation on the properties of internal waves was carried out.

Finally, a large part of the observations of the Snellius Expedition in the Netherlands East Indies (1929–1930) is still being worked up.

G 3.1

Oceanography in Finland

By

E. PALMÉN

Institute of Marine Research, Helsinki

Since 1939 Oceanography in Finland has worked under rather difficult conditions because of the war and the loss of large coastal regions. Many investigations concentrated in the Finnish Institute of Marine Research have, however, been continued or finished. The Institute has continued the regular oceanographic observations in the Baltic regions. However, during the war, large interruptions were inevitable, and no real sea expeditions could be made after 1939.

Among these investigations the following may be mentioned:

Professor Kurt Buch has continued his studies of the carbonic-acid equilibrium in the Baltic Sea and the Northern Atlantic, and the results have been published in different papers; among them is a large paper printed in the "Fennia" series of the Geographical Society of Finland. He has also published a smaller paper on the carbonic acid of the air in the Arctic and sub-Arctic regions.

Dr. Gunnar Granqvist has made large harmonic analyses of the temperature and salinity variations of the Baltic waters; this work has not yet been finished.

In connection with an expedition in the Baltic Sea during the summer of 1939, special current measurements were carried out in order to study the inertia-oscillations in the seas. The material has been carefully studied at the Oceanographic Institute at Gothenburg and partly also in Finland, and the results, showing very clearly the existence and nature of the inertia-currents, have been published in Sweden by Börje

Kullenberg of the Oceanographic Institute at Gothenberg and by Ilmo Hela of the Finnish Institute of Marine Research. Dr. Ilmo Hela has also published a large study of the variations of the total amount of water in the Baltic Sea. In collaboration with Dr. S. E. Stenji he has published a study of the frequency of the different heights of the Baltic sea-level.

Professor Risto Jurva has continued his extended studies of the ice conditions in the Baltic.

The question of the tides in the Baltic Sea has been studied by Dr. Eugenie Lisitzin, who has published new tidal constants for different stations of the Northern Baltic. She has also made several investigations of the relationship between wind, current and water-level in the Baltic.

Professor E. Palmén has studied some problems concerning the wind effect on the sea surface for the case of strong density stratification.

A special study of the seasonal variations of temperature and salinity in the Baltic has been published by Dr. Heikki Simojoki.

Professor Rolf Witting finished some old investigations concerning the upheaval of the continent in Northern Europe and on the transparency and turbidity of the Baltic water.

G 4

The Snellius Expedition, 1929-30

The following papers concerning the scientific results of the Snellius research were published during the 1939–45 War.

Vol. II. Oceanographic Results. Part 1: Methods and Instruments.

Chapter I. The Oceanographic Instruments and the Accuracy of the Temperature Observations, by H. C. Hamaker. 1941.

Chapter II. The Determination of Chlorine and Oxygen Content, by H. J. Hardon. 1941.

The first chapter of Part 1 contains a description of the most important appliances and instruments, *i.e.* the big winches for serial observations and their situation on board, the water-bottles and especially the bottom water-bottles, which appeared to absorb oxygen from the enclosed water sample during the first months of the research. Much attention has been given to the reversing thermometers and the accuracy of the temperature observations, the normal error being of the order of 0·01° C.

Then follows the determination of Volume V. of the thermometers and the zero-point corrections. It appeared that in some cases large discrepancies existed between the values of Volume V. estimated during the cruise and those given by the constructors, Messrs. Richter and Wiese. The average change of the zero-point corrections was about 0·004° C. for periods of six to eight months.

After this the author considers the change in diameter of the meter wheels and the accuracy of the depth determinations; also by protected and unprotected thermometers. General error, 4 metres. He concludes by discussing the different sources of error and their influence on the interpretation of these observations.

In Chapter II. Hardon deals with the determination of the chlorine content of the sea-water and discusses the analysis, the accommodation (laboratory), the instruments, the titration, the calculation of the chlorine content, the salinity and the accuracy. Standard error for a single observation, 0·0078 $^{o}/_{oo}$.

In the last section of this chapter the author discusses in a similar way the determination of the oxygen content. Standard error for a single observation, 0·0315 cm.^{3} O_2/L.

Vol. II. Oceanographic Results. Part 2: Soundings and Bathymetric Charts. Chapter III. Echo Soundings, by Th. van Huystee. 1944.

In compliance with the wishes expressed by the International Geographical Congress, 1938, in Amsterdam this paper contains about 33,000 depth-figures, which have been determined by means of echo-soundings during the Snellius expedition.

The positions of these soundings have been fixed as follows. The ship's track has been reconstructed from the logbook and pegged out on charts, scale 1 : 500,000. The route-charts added to Vol. I., Chapter III., furnished useful help. It has been assumed that the ship followed a straight course between two positions estimated by dead reckoning or by astronomical and terrestrial fixing. On this route the sounding-points have been interpolated with the use of time-statements from the logbook and the time of every echo-sounding as taken from the sounding-registers. Next, the co-ordinates of the points were read on a measuring-instrument constructed for the purpose, which enabled a quick method of working and made reading in tenths of minutes on a scale of 1 : 500,000 possible. Those using the tables should not be misguided by this with regard to the absolute exactitude of the spot of the sounding-points, the error of which depends mainly on the determinations of the ship's position.

The crossing-points of the sounding-tracks repeatedly made possible a control of the exactitude of these determinations. No trial has been made to obtain a better linking-up of the depths where this was possible by shifting the routes. This would have led to a flattered result. After all it appeared that the cases in

which the depths on a crossing-point along one route deviate considerably from those along the other route are very scarce.

Vol. II. Oceanographic Results. Part 5: The Bottom-water. Chapter I. Introductory Remarks and Oxygen-content, by P. M. VAN RIEL. 1943.

This part of the Snellius reports may be regarded as a continuation of Vol. II., Part 2, Chapter II., which deals with the bottom configuration and the distribution of the potential temperature in *longitudinal sections* in relation with the flow of the bottom-water in the eastern half of the East Indian Archipelago.

In Part 5 the properties of the bottom-water *at all stations*, as well as their distribution in each inland sea separately and in the adjacent parts of both Oceans, will be considered.

Chapter I. of this Part appeared in 1943. It contains:

A. The bottom-water observations of previous expeditions in the Snellius area and a comparison of these observations with the Snellius results.

B. The observation-depths near the bottom deduced from 141 thermometer depths, 148 wire depths and 48 echo depths. The accuracy of these three methods.

C. The oxygen observations.

a. The various sources of errors and the total error.

b. Multiple observations near the bottom.

c. The distribution of oxygen in the bottom-water (Plate I). This coloured chart shows for bottom-depths exceeding 1000 m, how far the distribution confirms and amplifies the conclusions concerning the movement of the bottom-water in the area of research, based upon the distribution of potential temperature in vertical sections.

d. Several vertical sections, crossing the various thresholds and showing the part played by the Pacific Ocean, the Indian Ocean and the Southern China Sea in refreshening the deep water of the successive basins and troughs.

e. Comparison of the oxygen-content near the bottom with the mean content determined at corresponding depths in the open sea.

Vol. V. Geological Results. Part 3: Bottom Samples. Section I.: Collecting of the Samples and some General Aspects, by PH. H. KUENEN. *Section II.: The Composition and Distribution of the Samples*, by G. A. NEEB. 1943.

The first section describes the apparatus applied on board, the methods of wire-soundings, and the treatment of the samples on board and in the laboratory. The organic matter, chemical bulk analyses, radium analyses and water content are reviewed. The organic content is closely correlated with the amount of clay in the samples. The amounts are not very high. The radium content, on the other hand, is high as compared to shallow-water deposits, in spite of the high rate of sedimentation, but shows no relation to depth. A short treatment is given of stratification that is rare, rate of sedimentation that is high, indications of slumping that are scarce, and oceanographical factors governing the sedimentation. Estimates are made of the time required for renewal of the deep water in the basins. One to a few centuries appear likely.

In Section II. Miss Neeb describes the mineralogical methods of investigation and the classification of the samples that was used. After reviewing earlier research, a table is given of these and of the new samples. The latter shows depth, slope, coastal distance, some properties, and the classification.

Then follows a detailed description of the samples, grouped as: volcanic mud, terrigenous mud, globigerina ooze, coral and shallow-water deposits. Each group is subdivided. The mineralogical and biological compositions are given of each sample and a histogram of the mechanical composition. The distribution of volcanic material for each active volcano is traced. The terrigenous mineral grains are correlated with the geology of the islands. The rate of sedimentation is discussed, as determined by the amount deposited since dated volcanic eruptions. High figures are obtained. Röntgenographic research on the finer fractions reveals that these are composed of

terrigenous matter and that volcanic dust does not play a part in the clay fraction. Samples of which the sand fraction is entirely of volcanic origin may contain terrigenous matter in the clay fraction greatly in excess of the total of volcanic matter. The calcareous and siliceous organisms, as also the secondary minerals, are dealt with briefly. Determinations of species have not been undertaken. A summary brings out the main results of the investigation. The various types of sediment are illustrated by photographs and a coloured map shows the distribution. Another map gives the relative lime content of the samples as compared with the average for the entire region.

G 4.1

The Results of the Swedish Deep Sea Expedition up to 21st June 1948

By

HANS PETTERSSON
Leader of the Expedition

Core sampling by means of Kullenberg's piston corer, supplemented by an ordinary short corer for taking undisturbed samples from the uppermost sediment layers, has given excellent results. So far more than 100 long cores have been raised. With a maximum length of 18 metres, several of them exceed 15 metres in length and most of them display a distinct stratification. The first dozen cores, taken during the Atlantic crossing in July–August 1947, were sent back to Sweden for analysis. This has already given important results; Dr. O. Arrhenius has found remarkably great variations in the content of phosphates, which he believes may lead to conclusions regarding chronology; Dr. W. Schott, analysing very completely the foraminifera in a 1·7 metres core taken west of Madeira, has found unmistakable signs of strong variations in the temperature of the surface waters, which he attributes to the climatic changes in the last 170,000 years, which the investigated length of core is assumed to represent; Dr. Phleger of Woods Hole, also analysing for foraminifera, has found pronounced variations in a core from the Caribbean, which he assumes to be due to climatic changes in late Quaternary times. According to these results, the way to a co-ordination between the chronology of deep-sea deposits and the chronology of continental formations seems open.

Measurements of sediment thickness, by means of Weibull's

method of recording echoes from exploding depth-charges, have been successfully applied to the deep ocean bed. Very pronounced differences between the depth of the reflecting layers in the Atlantic Ocean and in the two other oceans are brought out by these results, the former values being in part much greater than the latter. A new type of depth-charge constructed so as to explode below the sediment surface, instead of some thousand metres above it, is now being tried. It appears to give more distinct deep echoes undisturbed by irregularities in the bottom surface.

Echograms, by means of the new "Marine Instruments" recorder specially designed for the expedition, have been successfully obtained down to depths exceeding 8000 metres (southern extremity of the Mindanao Deep). The echograms are already being utilized for supplying the I.H.B. in Monaco with data for new sheets of the Monaco Bathymetric Chart. Their study from a morphological point of view promises to give valuable results. Both for coring and for trawling operations, the instrument has proved indispensable as an indicator of the roughness of the bottom and of risks to the gear used.

The geothermometer, designed for measuring the totally unknown temperature gradient in the deep-sea deposits, has proved difficult to operate, since it requires especially favourable conditions of wind, swell and bottom structure. The instrument has to be plunged into the bottom sediment to a depth of 12 metres and left there for a length of time exceeding half an hour, in order to attain an equilibrium of temperature with the surrounding deposit. Nevertheless, two apparently successful shots have been made with it near the Equator in the central Pacific Ocean in depths exceeding 4000 metres. The results indicate somewhat higher values for the thermal gradient than the average from measurements on the continents. After technical improvements recently introduced, the instrument will be used also in the depths of the Atlantic Ocean.

Complete hydrographic sections across the equatorial current system, with deep temperature, salinity, oxygen, etc., series, have been made, four times in the Pacific and twice in the Indian Ocean. The preliminary working up on board has proved the data to be valuable for a detailed study of the

Equatorial Counter Current, the oxygen minimum below it and the strips of convergence and divergence of the surface water accompanying it.

In order to carry out *radium and uranium measurements* on ocean water, from different localities and depths, large-volume samples (20 litres) have been taken and the radium precipitated together with barium sulphate (Ra-free). Several of such precipitates, as well as concentrated water for uranium determinations by the fluorescence method, have been sent from the expedition to Göteborg and Vienna for analysis, now in progress. The importance played by the radioactive elements as time-keepers in the deposit and as a clue to their chronology and the rate of sedimentation (according to the hypothesis of ionium precipitation), which is evident from investigations made in Sweden and in the U.S.A., enhances the need for more data on the content of these elements both in the deposits and in the water.

Light measurements and studies of suspended particles have been made along the course, partly by submarine light-meters with rectifying cells, partly, in the deeper layers, by the photographic method. The ultraviolet components of submarine daylight near the surface have been measured for the first time, by means of a special instrument (N. G. Jerlow). The particles suspended in the water have been studied by means of the Tyndall method, proving well-defined layers of higher turbidity to be present also in great depths.

G 5

Travaux effectués en Belgique de 1939 à 1948

Par

J. LAMOEN

Laboratoire de Recherches Hydrauliques

(1) R. Vekemans.

"Récapitulation décennale des observations de marée dans le bassin de l'Escaut maritime pour la période 1931–1940." Annales des Travaux Publics de Belgique, août 1946.

Les Annales des Travaux Publics de Belgique publient régulièrement les résultats des observations faites sur les rivières à marée du bassin de l'Escaut. L'étude actuelle présente, pour quelque 35 postes d'observation pris sur l'Escaut, les Nèthes, le Rupel, la Senne, la Dyle et la Durme, les tableaux et graphiques donnant:

(1) Les valeurs moyennes (annuelles, ainsi que pour la décennale envisagée) et les valeurs extrêmes des hautes et basses eaux, les durées du gagnant et du perdant, les décalages dans le temps par rapport à Flessingue, etc.

(2) Les valeurs moyennes et extrêmes des hautes et basses eaux par saison.

(3) Les marées spéciales avec leurs caractéristiques.

(4) Des courbes locales pour divers postes et des courbes instantanées à divers instants.

Ces données sont fournies par 18 tableaux et 12 feuillets de graphiques.

L'auteur ne se borne pas à présenter ces observations; il en discute également les principaux résultats.

Il signale notamment l'influence sur l'amplitude des marées (en augmentation par rapport aux périodes précédentes) de

l'affaissement tectonique de la partie de l'Escaut à l'aval d'Anvers, affaissement qu'un nouveau nivellement de précision semble établir.

Il montre les diverses modifications des marées dues aux transformations des caractéristiques hydrauliques du fleuve et de ses affluents (endiguements, régularisations, etc.).

Il fait remarquer que la vitesse de propagation de l'onde augmente depuis le début des observations en 1880.

Il étudie l'influence des débits d'amont en utilisant la méthode des écarts statistiques.

L'auteur termine par un examen de la situation de la Durme, qui s'est d'abord améliorée sous l'action de travaux de régularisation, mais dont la situation a maintenant repris sa marche régressive.

(2) H. Holsters.

"Le calcul du mouvement non-permanent dans les rivières par la méthode dite des lignes d'influence." "Revue Générale de l'Hydraulique," janvier 1947 à octobre 1947.

Dans ce mémoire l'auteur met à profit une méthode d'intégration graphique des équations aux dérivées partielles exposée par J. Massau dans une série de publications parues de 1900 à 1905 dans les "Annales de l'Association des Ingénieurs sortis des Ecoles spéciales de Gand."

Dans ces écrits Massau montre que, dans les problèmes de la mécanique appliquée qui dépendent d'équations aux dérivées partielles, les conditions aux limites présentent des discontinuités, que ces discontinuités se propagent selon les caractéristiques et que la solution d'un problème de cette espèce s'obtient en divisant le domaine des variables en compartiments et en déterminant une solution analytique pour chaque compartiment. Dans le cas de deux variables indépendantes, les fonctions inconnues sont représentées par des assemblages de surfaces analytiques analogues aux polyèdres à faces planes ou curvilignes, les faces adjacentes se coupant ou se touchant selon l'ordre des caractéristiques de séparation.

L'intégration graphique consiste dans le calcul, de proche en proche, et par différences finies assez petites, des fonctions inconnues (h et q par ex. si nous nous limitons au cas du mouve-

ment non permanent dans les cours d'eau, h étant la cote atteinte par la surface libre et q le débit) aux noeuds d'un réseau suffisamment serré, formé de lignes caractéristiques engendrées par les discontinuités des courbes-limites.

Rigoureusement parlant, le tracé des caractéristiques dépend de la profondeur moyenne et de la vitesse du courant, éléments qui varient tous deux avec le temps. Mais Mr. Holsters a montré sur de nombreux exemples que, pour les courants non permanents tout au moins, l'on obtient une approximation très satisfaisante en adoptant, comme base du calcul, un réseau de lignes caractéristiques (qu'il appelle "lignes d'influence," dénomination qui les distingue des tracés rigoureusement exacts) correspondant à une vitesse de courant nulle et à une profondeur invariable dans le temps. Pour les rivières maritimes, par exemple, il est naturel de choisir la profondeur moyenne du profil sous la cote de mi-marée.

La méthode exposée s'applique aux mouvements purement périodiques (régime moyen de la marée et modifications apportées à ce régime par l'exécution de divers travaux) comme aux phénomènes transitoires (crues) et aux questions les plus difficiles qui peuvent se présenter en ces matières, notamment la prédétermination de l'abaissement des côtes de marée haute que l'on obtient avec des réservoirs inondables et du volume d'eau recueilli dans les dits réservoirs. La méthode est susceptible aussi de servir lors d'études pour l'établissement d'installations pour l'emploi de la force des marées et, si l'on se rapporte aux écrits de Massau, on constate que son champ d'application dépasse même largement le cadre des courants non permanents.

Le mémoire comporte une étude comparative où sont confrontés les résultats, d'une part, de calculs conduits selon la méthode de l'auteur et, d'autre part, d'essais sur modèles réduits exécutés au Laboratoire de Recherches Hydrauliques des Ponts et Chaussées de Belgique, à Borgerhout-Anvers.

(3) Le Laboratoire de Recherches Hydrauliques des Ponts et Chaussées a réalisé un grand modèle reproduisant l'Escaut maritime depuis son origine amont au barrage de Gentbrugge (Gand) jusqu'à son embouchure dans la mer du Nord à Flessingue, soit sur un parcours de 160 km., sans compter les affluents.

L'Escaut, ainsi que tous ses tributaires maritimes, ont été reproduits selon les levés hydrographiques. L'échelle des dimensions en plan est $\frac{1}{1250}$ et l'échelle des profondeurs $\frac{1}{70}$. L'appareillage qui reproduit la marée de la nature est installé à l'embouchure en mer du modèle. Des marégraphes sont placés en des endroits où il existe des appareils analogues dans la réalité. Le modèle a été construit pour étudier divers problèmes techniques qui se posent dans le bassin de l'Escaut maritime.

Jusqu'à présent les résultats des expériences n'ont pas été publiés; les études ne sont d'ailleurs pas terminées. Pour une description illustrée succincte du modèle on consultera le Bulletin de l'Association Internationale Permanente des Congrès de Navigation (numéro de janvier 1948).

(4) Le susdit Laboratoire a effectué, pendant une période de quelques années, des observations sur les eaux de l'Escaut maritime et de ses affluents soumis à marée, en mesurant principalement leur salinité et leur teneur en matières solides en suspension. Les résultats ont fait l'objet de rapports au Ministère des Travaux Publics de Belgique; ces rapports n'ont pas été publiés.

G 6

The Present Status of Oceanography in Canada

By

H. B. HACHEY

Canadian Joint Committee on Oceanography

On the basis of her population Canada has an enormous length of coast line, which is separated into three distinct regions by Alaska and Newfoundland. Of these three regions, east, north and west, the north or Arctic coast is by far the longest. Utilitarian aspects of the subject have always directed attention to the extremely practical bearing of oceanography on fisheries and shipping, with the result that the Fisheries Research Board of Canada and the Hydrographic Service of Canada have been responsible for the development of the subject as we know it in Canada to-day.

Maritime development of northern transportation routes to Asia and Europe, and problems of continental defence have focused attention on the land and water masses of the arctic and sub-arctic regions of Canada. The expansion and development of a Canadian Navy has also directed further attention to the sea, with the result that oceanography has received considerable impetus during the last few years.

The Canadian Joint Committee on Oceanography has been recently organized, comprised of representatives of the Fisheries Research Board of Canada, the Royal Canadian Navy, and the National Research Council. It is expected that the Canadian Hydrographic Service and the Meteorological Service of Canada will shortly appoint representatives. Under the Joint Committee, which is an administrative body, function two oceanographic groups, one on the Atlantic and one on the Pacific. The present status of oceanography in Canada is at a comparatively high level.

After mentioning the aspects of oceanography of especial interest to Canada, this paper reviews the great contributions to knowledge of the oceans surrounding Canada made by the vessels of other nations. A general description of the ocean circulation off Canadian coasts is given, with mention of special problems that require attention.

G 6.1

Oceanographical Work of the Australian Council for Scientific and Industrial Research

By

D. ROCHFORD

Division of Fisheries, Cronulla, New South Wales

From its inception in 1938, the C.S.I.R. Fisheries endeavoured to obtain as much hydrological information about the waters of the East Australian area as possible. However, demands on its research vessel were such that prior to 1940 little planned oceanographical work was possible.

The uncertainties of the early war years, and the difficulty of maintaining a research vessel under these conditions, obliged C.S.I.R. Fisheries to forego the use of its research vessel about the middle of 1942.

Since that date the oceanographical programme in this area has been reduced to evaluation of the seasonal cycle of hydrological conditions in the onshore waters of East Australia. This programme has been supplemented by an intensive investigation of the hydrology of estuarine and fluveatile waters in this area. Since 1941 an automatic tide recorder, of a pattern similar to that used by the United States Geodetic Survey, has been in operation at the entrance to Port Hacking.

Reduction of this tidal data to mean sea-level values up to the end of 1947 has been completed and will shortly be published.

Since 1944 a similar programme of onshore hydrological investigation has been carried out in the South-West Australian area.

Commencing towards the end of 1947, a deep-sea programme in this area, consisting of quarterly traverses of 100 to 150 miles, off Geraldton, Fremantle, and Albany, has been carried out.

Two research vessels will shortly be in commission in the Coral–Arafura Seas area. An attempt will be made to maintain a continuous programme in the Arafura Sea adjoining Thursday Island, together with a bi-annual line of stations across the Coral Sea basin from Cairns to South-West Cape, New Guinea. It is expected that a deep-sea programme in the East Australian area will be commenced.

G 7

Tidal Activities of the Survey of India

By

B. L. GULATEE

Research Institute, Survey of India

Tide-gauge observations were started in India in 1874, and at one time or another automatic tide-gauges (Newman's type) have worked at 42 ports for various periods (normally about five years). These tide-gauges were started primarily for the purpose of affording data for tidal predictions and for providing a datum for hydrographic surveys as well as for the level net of India. Except for a few major ports, the work at all the remaining ports was stopped before the end of last century.

The control of tidal observations was entrusted to the Survey of India in 1879, when a tide-predicting machine with 24 components was constructed for the Government of India and set up at the Stores Department, Lambeth, London, and later on at the National Physical Laboratory, Teddington. Data were supplied from Dehra Dun, and the tide tables were published in England till 1921 when the machine was taken over by the Geodetic Branch, Survey of India, Dehra Dun. Since then, the compilation and publication of the annual tide tables of the Indian Ocean have been the concern of the Survey of India. These tide tables contain a total of 67 ports of which 39 ports lying between Suez and Singapore are predicted by the Survey of India and the remaining are obtained on an exchange basis from the Hydrographic Departments of foreign countries. In addition, separate tidal pamphlets are published for Bombay, the Hooghly River, and the Rangoon Rivers.

During the World War II. tidal predictions in the form of tidal charts, from which the height of the water can be read at any time, were prepared for quite a number of ports in the Far

Eastern waters for operational purposes. These predictions were supplied exclusively to the Eastern Fleet Naval Headquarters and were based on harmonic data of only four main tidal components, M_2, S_2, K_1 and O_1, from which eleven more components were derived theoretically.

For most of the ports the data on which our present predictions are based are over fifty years old. It is, therefore, considered that some investigation is needed to see if any local changes in level of sea-bed or configuration of land significant enough to affect the predictions have taken place. Actuals are not being recorded at a majority of the ports to enable comparison to be made with predicted values, and in some cases, where actuals for some years are available, experience has shown that too much reliance cannot be placed on them on account of the unreliability of the tide-watchers. As a preliminary step towards these investigations, a touring tidal detachment has been formed this year which will visit several primary and secondary ports to obtain hourly tidal observations for about a month at each port. These observations will be analysed by the Admiralty method in the Survey Research Institute, Dehra Dun, and it is hoped that valuable data will be obtained in this way.

A huge mass of valuable material in the form of original tide-gauge records has accumulated for the study of variations of mean sea-level, but no systematic work on this subject has been undertaken. In fact, for a number of years the mean sea-level has not been computed at all. Of late, at the request of Mr. Legrand and the International Oceanographic Association, monthly and annual mean sea-levels have been supplied for publication in *Publications Scientifiques*, but due to lack of personnel the deduction of mean sea-level has been in some cases only from high and low waters and in others by some sort of a makeshift method. For the same reason, no attempt has been made to solve problems as accounting quantitatively for the fluctuations in sea-level in terms of meteorological conditions and variations in physical conditions of sea-water, or delineating whether the slow variation of mean sea-level along the eastern and western coasts of India are in sympathy or not.

The dismantling of the majority of the tide-gauge

observatories was unfortunate. Their important scientific objective (so valuable to the geologists and others), viz. the delineation of relative movements of land and sea, appears to have been lost sight of. If a large number of the observatories had been kept on up to the present moment, valuable material would have been available for investigating the coastal stability of India. Already, the variations of mean sea-level have been used to investigate whether deltaic Bengal has been in a gradual state of subsidence, as has been suspected by several authorities. From 1880 onwards, tidal records at Kidderpore have shown that, up to 1930, land had been rising relative to water at the rate of about 2 inches per decade. From 1930 onwards, depression of the land has started, but a preliminary study has shown that this depression has not persisted and that mean sea-level is tending to assume an oscillatory character. The number of active tidal observatories is only three along the vast coast-line of India, Pakistan, and Burma, and is highly inadequate.

Oceanographic activities in India, so far as off-shore surveys and echo-soundings are concerned, are carried out by the Marine Survey of India (R.I.N.). In the past there was not much liaison between the Survey of India and the Navy, but a beginning has been made and the two departments are now in touch with each other's programmes.

G 8

Preliminary Campaign in the Alborán Sea

By

N. MENENDEZ

Spanish Institute of Oceanography

The number of measurements and stations realized up to this date in the Gibraltar Strait and the adjoining seas is really great; its density is comparable with those of other regions of the sea well known, but the information that one can get about the Strait is very poor. The main reason for this is that the measurements were taken in an incoherent way, without a uniform plan, and in seasons and conditions completely different, and this has been fatal, owing to the fact of the very variable and complicated character that is characteristic of the dynamics of the Gibraltar Strait. Trying to compare the results that are obtained at each station and to get a result out of them becomes a puzzle-game; each piece has been constructed casually and does not go with the rest.

The Spanish Institute of Oceanography has proposed to start the study all over again, following a plan from now on.

The extent of the Gibraltar Strait and the adjoining seas is not great in itself, but it is big having regard to variability of the dynamics, as well in space as in time, and this is the point of view that one has to adopt in measuring the extent of an oceanographic study. For this reason we thought it best to divide the Strait into regions that on the one hand must be small enough so that each of them can be studied in one single campaign, and on the other hand great enough so that each of them can include various concrete problems, independent of each other, but in a way that they afterwards can be put together.

We have gathered and studied all the data that we could get up till now, and according to them we have divided the Gibraltar

Strait into three regions: the region of the Alborán Sea, the region of the Centre and the region of the Spanish Sea.

The region of the Alborán Sea extends from the meridian that passes through this island up the one that passes through Tarifa. From a morphological point of view it is characterized by the basin of Alborán. In this the Mediterranean water is predominant. The tide is not of the Atlantic type. The difference of the two waters, Atlantic and Mediterranean, is extraordinarily outstanding.

Originally, we used to subdivide this region into three other regions, but as a consequence of the campaign of which I give a brief account we think that this division must not continue in all details. The first zone is limited by the parallel 36° N. and the meridian of Ceuta; in this zone, according to the preliminary data, there seems to be no Atlantic water. The southern zone, limited by the same parallel, the shores of Africa and the meridian of Ceuta, is characterized by the superficial Atlantic current. Finally, the occidental zone of the Alborán Sea, between the meridian of Ceuta and the first barrier of the Strait at 5° 44′ W. Long., is characterized by the immersion of the Mediterranean water and an elevation of the more heavy bottom water, a kind of great submarine mascaret, whose presence is evident in various observations, even if in some it is missing; it seems to have great fluctuations in extent and position.

The central region is between the 5° 44′ W. and 6° 20′ W. From a morphological point of view this region is characterized by unevenness of the bottom and by the presence of two barriers; the first one is traversed by one single channel and the second is bounded on the north and south by two channels. It is here that the mixture of Mediterranean and Atlantic waters is most accentuated. Consequently the study of this central region is difficult, and one has to employ direct methods that can go with the turbulent nature of its dynamics. This region can be divided into two zones, the more oriental where the turbulence is greater, and the more occidental corresponding to the two channels of the Majuan Bank, where the water begins to be more stratified.

The region of the Spanish Sea, of a much softer morphology

than the one mentioned, is extended to the meridian of Cape San Vicente in the south-west of Portugal. There one can detect the layer of Mediterranean influence that afterwards falls into the Atlantic. The study of this region is more simple, as one can see on the S–T diagram of neighbouring stations.

The Spanish Institute of Oceanography proposes to carry out successively the study of these regions, beginning with that of the Sea of Alborán. Their first intention is to delimit the characteristics used to define them, obtain information regarding their dynamic behaviour at different times of the year and, in accordance with the results obtained, select the standard stations necessary to watch the dynamics of each one of these regions and of those in which continuous and routine measurements are to be made during many years, so as to obtain sufficient information on the currents in the Straits and their variation in the course of time.

Campaigns in the Sea of Alborán

April 1947 and January–February 1948

In accordance with the plan established, the aim of this preliminary campaign is to fix the limits of zones I, II, and III, into which the Sea of Alborán has been divided, for subsequent systematic study. We may consider the isohaline $36{\cdot}5^{\circ}/_{\circ\circ}$ as the inferior limit of the purely Atlantic water, and $37{\cdot}5^{\circ}/_{\circ\circ}$ as the superior limit of the purely Mediterranean water, since the salinity $36{\cdot}4^{\circ}/_{\circ\circ}$ corresponds to the surface average in the south of the Sea of Cadiz, where there exists no Mediterranean influence whatever, and $37{\cdot}5^{\circ}/_{\circ\circ}$ is the approximate average value of surface salinity in the Balearic Sea of Valencia, where any Atlantic influence is incredible. Between both isohalines there exists an ample zone of mixed type of water.

As a general feature of the Alborán Sea we can establish the presence of two kinds of water, obviously different. It is not unusual in an interval of only 50 metres to find sudden changes of $2{\cdot}0^{\circ}/_{\circ\circ}$ in the salinity and 3° C. in the temperature. These great values of the gradient are coincident with the isohaline of the $37{\cdot}5^{\circ}/_{\circ\circ}$.

Generally we can say that the water with Atlantic influence

is extended all over the Sea of Alborán, but while in the north it remains entirely superficial, in the south it sinks toward the parallel 36° N., arriving at a maximum depth toward 35° 30′ N. and turning upwards as it gets nearer the African shore. While the mixed water goes deeper there is, of course, a purely Atlantic water layer. The inferior limit of this has its deepest part towards the middle of the southern zone of the Alborán Sea, from this point it gets less in thickness, either North or South, East or West. So we know the existence, in the southern part, of an anticyclonic movement of the pure Atlantic water.

We may conclude from these campaigns that the Atlantic influence extends throughout the Sea of Alborán, and therefore the division of its eastern part in zones I and II is not sufficiently justified, as both present the same specific problem. On the other hand, the eastern limitation of the Sea of Alborán by the meridian of Alborán does not appear to be justified. It seems to be more reasonable that this limit should extend further to the east until the influence of Atlantic water forming the surface-layer found to the north of the Sea of Alborán, relatively calm, disappears, and the eastward-flowing Atlantic current is clearly defined. We will go on studying the Alborán Sea, making four standard profiles in each season of the year, from north to south, following approximately the lines of meridians 2°00, 3°00, 3°40, and 5°10, and another from east to west. In this way we think that we can now study thoroughly this region in which at present we are interested.

G 9.1

Thermal Structure of the Surface Layers of the Sea near the Antarctic Convergence

By

E. C. LA FOND

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The thermal structure of the sea near the Antarctic Convergence was investigated during the southern summer, 1946–1947, by means of bathythermograph observations.

The location of the Convergence on five crossings ranged between 60° 24′ and 63° 50′ S. Three crossings in the same longitude showed a southward displacement of the Convergence from December to February followed by a northward displacement by the end of February.

The sea-surface temperature from north to south decreases sharply at the Convergence. The temperature encountered at the Convergence was 1·8 to 3·2° C. Thermal structure below the surface indicates an instrusion of cold sub-surface water at a depth of about 100 meters which in some cases extends two or three degrees farther north than the location of the surface Convergence. The layer of sub-surface temperature minimum is the residual of winter-cooled surface water with a temperature of less than 0° C. In the transition layer between the cold water and the Antarctic circumpolar water the temperature increases about 2° C. in the first 50 metres of the layer. The thermal boundaries are irregular and are influenced by internal waves.

G 9.2

Sur les Variations de Salinité et de Temperature de l'Eau de Mer de Surface sur un Point du Littoral Indochinois

Par

R. SERENE

Institut Océanographique de l'Indochine

Cette étude intéresse un point particulier des recherches consacrées par l'Institut Océanographique de l'Indochine à l'océanographie physique de la Mer de Chine; je donne auparavant un rapide aperçu des travaux de cette institution.

Dès 1927, l'Institut Océanographique de l'Indochine, par des mesures de températures de l'eau de mer de la Mer de Chine, en relation avec des observations sur les courants, le jeu des moussons, et le relief sous-marin, établissait l'existence d'un courant de fond qui, butant contre la falaise du plateau continental, fait affleurer à proximité du littoral indochinois des eaux froides auxquelles correspond une faune de latitude plus élevée.

A partir de 1931, Mr. Chevey a effectué régulièrement des observations comprenant des mesures (*a*) de température en surface et en profondeur dans la Mer de Chine au cours des croisières du "De Lanessan"; (*b*) de température journalière en surface en un point fixe du litteral annamite: appontement de Cauda; (*c*) de température de surface dispersée dans la Mer de Chine en relation avec les croisières occasionnelles de certains bateaux. (Mr. Serene en 1933–34 sur l'Astrolabe, divers navires de la Marine Nationale ou de commerce.) Plus de 10,000 mesures ont ainsi été faites, dont un grand nombre ont été communiquées au Comité d'Océanographie Physique du

Pacifique et la plupart publiées dans les Notes de l'Institut Océanographique de l'Indochine.

Partant de ces mesures, Mr. CHEVEY a publié: (*a*) des courbes de variations de température de l'eau de mer de surface à Cauda; (*b*) des coupes hydrologiques de la Mer de Chine avec tracés des isothermes en profondeur; (*c*) des tracés en surface des isothermes de la Mer de Chine. En 1935, Mr. SERENE ajoute à ces observations des mesures de salinité par la méthode réfractométrique et les publications se complètent: (*a*) des coupes hydrologiques avec les isohalines en profondeur, (*b*) des tracés en surface des isohalines.

En 1935, faisant une première synthèse de ces résultats, Mr. CHEVEY, distinguant trois régions d'études: le Golfe du Tonkin, le Golfe du Siam et la Côte Annamite, propose une classification des eaux marines indochinoises en eaux deltaïques, eaux cotières, eaux du large; définies dans une même région en fonction de leur salinité et de leur température. Par exemple au golfe du Tonkin, les eaux deltaïques sont de $> 25°$ et $< 32°/_{oo}$, les eaux cotières sont de $> 26°$ et 32 à $33°/_{oo}$, les eaux du large sont de 22 à $25°$ et $> 33°/_{oo}$.

Ces études soumises aux possiblités de croisières du bateau océanographique n'ont pu être poursuivies; par contre pour le litteral annamite, le laboratoire de Cauda a continué son étude du régime de la baie de Nhatrang. Les résultats de cette étude des variations saisonnières de température et de salinité de l'eau de mer sur un point du litteral annamite font l'objet de cette communication.

* * *

De 1936 à 1943, les mesures journalières de température et salinité de l'eau de mer de surface étaient faites à l'extrémité de l'appontement situé à proximité immédiate du laboratoire de la Station Maritime de Cauda par longitude E. 109° 12′ 40″, latitude N. 12° 12′ 24″. Les mesures effectuées à 8^h et 16^h permettent de juger de l'importance de la variation journalière de température au long de l'année. Elle est de 1° en moyenne, mais atteint parfois en Juillet–Août et Janvier–Février jusqu'à 4°.

De ces mesures biquotidiennes on a déduit la température et la salinité moyennes bimensuelles qui, représentées sur des graphiques, ont été rapprochées de la somme mensuelle des

chutes d'eau de pluie à la même station. Les résultats de ces mesures et les courbes ainsi obtenues ont été publiés dans les rapports annuels de l'Institut Océanographique de l'Indochine. Leur examen montre les variations saisonnières de température et de salinité et leurs relations avec les chutes de pluie. Les courbes des pluies et des salinités sont toujours complémentaires témoignant de la sensibilité des eaux littorales aux précipitations locales. Aux plus grandes chutes de pluies (800 mm.) en Novembre généralement correspond le minimum de salinité (26°/$_{oo}$). Certaines années (1936) la chute de pluie de Novembre étant plus faible (400 mm.), la salinité ne descend pas au dessous de 30°/$_{oo}$. Si elle atteint 500 mm. (1937), la salinité tombe à 28°/$_{oo}$. En moyenne dans l'année, la salinité varie entre 33°/$_{oo}$ en Juin-Juillet et 29°/$_{oo}$ en Novembre.

Si l'on superpose les courbes de variation de température d'une dizaine d'années on reconnait dans l'ensemble sur chacune une montée thermique de printemps de Février à Mai (de 25° à 30°)—un plateau de Mai à Septembre (autour de 30°) avec un creux en Juillet (jusqu'à 27°) et une chute d'Octobre à Décembre (de 30° à 25°). Chaque année on retrouve deux maximums thermiques, l'un en Mai de printemps, l'autre en Août d'automne; le maximum de Mai–Juin étant légèrement plus élevé (1° ou 1/2°) que celui d'Août.

La montée thermique de printemps s'amerce d'ordinaire en Février ou Mars, exceptionnellement en Janvier, voire Décembre; dans ce dernier cas elle est régulière et s'échelonne sur cinq mois; sinon elle est plus brusque et passe en trois mois de 25° à 30°. La descente est toujours beaucoup plus lente. Le minimum se trouve suivant les années en Janvier ou Février, il est en moyenne de 24°; les maximums étant en moyenne de 30°. Certaines années plus chaudes (1936) le maximum de Mai atteint 32°. La variation annuelle moyenne est de 6°.

H 1

On the Reliability of the Derived Values of Mean Sea-Level

By

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The changes of sea-level caused by the winds and the variations of the atmospheric pressure may give rise to fluctuation of derived values of the mean sea-level, but the changes will remain within such limits that they will add no variation of secular character to the variations of the mean sea-level.

The sea-level usually is determined in relation to a benchmark and to fixed points at some distance from the coast. In the case where the points consist of bolts placed in the primitive rock, and the recorded values of the sea-level are referred to such points in a proper way, reliable values of the sea-level may be obtained. But in other cases where the fixed points consist of bolts cast in cement blocks that have to be established in more or less soft soil their heights may vary.

Some measurements on a Danish island (clay) of the height differences between five fixed points, consisting of brass bolts at a depth of 66–108 cm. cast in cement blocks $\frac{1}{2}$ m. thick, have, for instance, shown that the difference between two of the points in the course of twenty-four years has changed 19 mm., the first measurement being made half a year after the establishment of the points. As to the absolute value of their variation in height, no information can be given.

In this connection it can be remarked that, in order to secure that the height of the fixed points to which the recorded values at the Danish coasts are referred as far as possible remains unaltered, fixed points with bolts at a depth of 150 cm. and the

base of the cement block at a depth of 250 cm. have earlier been or will be established, to replace the fixed points hitherto in use where the bolt and the base were at a depth of 90 and 140–160 cm. respectively.

If the fixed points to which the recorded values of sea-level are referred vary considerably in height in the course of time, a systematic error will be introduced in the secular variation of the mean sea-level, and further it will not be possible to determine a correct value of the eustatic variation. It would therefore be of interest if all data on sea-level observations were accompanied by such information concerning the points to which the recorded values have been referred that the investigator may select the data which are most fit for the problem he is going to treat.

H 1.1

Mean Sea-level as a Geophysical Datum

By

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The determination of the basic datum of mean sea-level is a job for the tidal specialist. Until recently this datum was of minor importance in tidal research, and hence no well-defined procedure was developed for the precise determination of mean sea-level. More recently, however, mean sea-level as a datum has become important in geophysical investigations. Fortunately, there are now available systematic tide observations from automatic tide gauges for a number of years that make possible detailed investigation.

In this connection, I wish to point out that systematic observations require periodic checks between bench marks and tide staff to detect changes in elevation of the zero of the tide staff. At each primary tide station it is recommended that not less than five bench marks be established, that they be so located that it is unlikely that all bench marks will be destroyed by a common cause, and levels be executed yearly or oftener between the staff and the bench marks.

It is convenient to use the expressions daily, weekly, monthly and yearly sea-level. These terms denote, respectively, the sea-level derived by averaging the hourly heights of the tide for the period of a day, week, month and year.

Sea-level from day to day may fluctuate by more than a foot because of meteorological changes. From month to month the fluctuations in sea-level may vary as much as half a foot and it is well known that this monthly fluctuation at many places has a large element of periodicity; that is, within a year there is a cyclic change in sea-level represented by the tidal harmonic constants Sa and Ssa.

The larger fluctuations due to wind and weather tend to

balance during a year and the seasonal change is eliminated. Hence, one may expect the fluctuations in sea-level from year to year to be relatively small.

At five stations on the Atlantic coast of the United States, from Boston, Mass., to Mayport, Florida, the fluctuations in sea-level from year to year vary from a few hundredths of a foot to as much as two-tenths of a foot. The larger fluctuations are obviously caused by the disturbing effects of changing meteorological conditions. These disturbing effects can be averaged by deriving moving means and a more or less smooth curve drawn. A very decided progressive rise in sea-level of 0·35 foot is evident along the stretch of the coast since 1930. Further examination indicates that the fluctuations in sea-level from year to year at places relatively near each other is roughly the same. New York and Baltimore, 150 miles apart by airline, are 400 miles via the sea. New York is near the open sea, while Baltimore on Chesapeake Bay is 150 miles from the open sea. Yet the fluctuations in sea-level are roughly the same. The years 1903, 1910 and 1919 were years of high sea-level at New York, and likewise at Baltimore; 1912 and 1930 were years of low sea-level at Baltimore, and likewise at New York.

At four stations located on the coast of the Gulf of Mexico, covering a stretch of about a thousand miles, the fluctuations from year to year are much the same as on the Atlantic coast, and there is, likewise, a progressive rise in sea-level in recent years. At Galveston this rise is at a more rapid rate than at the other stations. Additional tide stations will be established in this area to determine the extent of this rapid rate of change in sea-level.

At four stations on the Pacific coast of the United States, including one station in Alaska, the fluctuations from year to year are about the same magnitude as on the Atlantic coast, but the progressive change in sea-level is not nearly so pronounced. Indeed, at Ketchikan, Alaska, sea-level appears to be falling during the last ten years.

It is evident that sea-level fluctuates from day to day, month to month, and year to year. In addition it is subject to slow secular changes, rising in some places and falling in

others. Hence, it follows that the concept of mean sea-level as a fixed and unchanging datum good for all time is not valid.

Moreover, sea-level determined at one place from a few years of observations and at another near-by place from a different period of years will not give comparable mean sea-levels. To derive a mean sea-level that has a precise meaning it must be determined from a definite number of years, and furthermore it must be based on a given epoch.

The question regarding the number of years of observations required to establish a basic datum has been resolved by adopting the theoretical period of time required for the moon to complete a cycle involving the longitude of the moon's node. Hence, 19 years may be taken as constituting a primary determination of mean sea-level. As to the epoch to be used, any one agreed upon will serve. In the Coast and Geodetic Survey we are now using the epoch 1924–42.

With the adoption of a definite number of years as constituting a primary determination of mean sea-level, and basing it on a given epoch, it is possible to correlate this datum for large regions without the necessity of 19 years of observations at all places where this datum may be desired. An example will make this clear.

In 1933 sea-level was determined by means of a year of tide observations at Los Angeles, California, and was found to be 6·27 feet on the tide staff. Eight years later, in 1941, another year of observations was obtained on a tide staff that was set at the same elevation as in 1933. In 1941 sea-level for the year was found to be 6·73 feet, or 0·46 foot higher than in 1933. Which one of these values is to be used as the datum of mean sea-level?

To correct these determinations to a 19-year mean and to the epoch 1924–42, adopted for the whole Pacific coast, we may use the results from the primary tide station at San Diego, which is a little over 100 miles south-east of Los Angeles. At San Diego mean sea-level for the 19-year period 1924–42 is 6·31 feet on the tide staff. For the years 1933 and 1941 sea-level at San Diego was, respectively, 6·15 feet and 6·58 feet. In other words, for the year 1933 sea-level at San Diego was 0·16 foot below its mean value and for 1941 it was 0·27 foot

above its mean value. Applying these corrections to the observations at Los Angeles we derive from the 1933 observations a mean sea-level of 6·43 feet, and from the 1941 observations 6·46 feet. Two yearly values of mean sea-level that differed by 0·46 foot differ by only 0·03 foot when corrected.

The years 1933 and 1941 were chosen for illustration because they represent, respectively, the lowest and highest yearly sea-levels at Los Angeles for the past twenty-five years. For the 19-year period 1924–42, mean sea-level computed from tide observations at Los Angeles is 6·48 feet on the staff. So that each year's observations used for illustration which differed by 0·21 foot and 0·25 foot, respectively, from the 19-year mean when corrected by the basic station at San Diego disagreed by 0·05 foot and 0·02 foot.

The definition of mean sea-level, based on a specified number of years of observation during a stated epoch, makes it a geophysical datum.

H 2

Some Peculiar Tidal Variations

By

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An analysis of the data for the recording gauge at Esbjerg (western part of Denmark) has been undertaken. The difference between high water and low water (tidal range) at Esbjerg is about 150 cm. in average, the amplitude of M_2 being about 68 cm. Besides the well-known 18·6 year variation of the tidal range, two considerable variations have been established: In the course of the years from 1890 to 1940 the tidal range has increased by about 13 per cent.; further, the tidal range is found to vary with the mean height of the sea-level. It is shown that the tidal range is 3 cm. greater when the mean height of sea-level —on account of weather and other conditions—is 10 cm. lower, and *vice versa*.

The recording gauge at Esbjerg has been in function since 1889; it is situated inside Fano and other small islands. The water in this part of the sea is rather shallow, but it is traversed by some channels. The threshold depth between the sea at the recording gauge and the North Sea is $6\frac{1}{2}$ m.

It has not yet been possible to explain the increase of the tidal range in the course of the years, but the phenomenon may be connected with the general transgression of the whole North Sea. Neither has the correlation between the height of the sea-level and the tidal range been explained, but there are indications supporting the view that the cause is the change of the streams just west of the above-mentioned islands originating from the pressure of the winds on the waves.

The records from the other recording gauge stations in Denmark functioning in the same period as the station at Esbjerg do not show variations of the above-mentioned kind. This may chiefly be due to the fact that the tide at these stations is much smaller than at Esbjerg, so that it should be difficult to ascertain such variations.

H 2.1

Note sur la Marée de la Manche Centrale

Par

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A l'occasion de dépouillement de mesures de courants de marée relativement nombreuses effectuées dans la Manche Centrale, par les marines britannique et française essentiellement, on s'est posé le problème de la détermination de certaines caractéristiques de la marée, qui varie beaucoup dans cette zone, à partir des courbes types (obtenues en divers points de la côte française en traçant la courbe moyenne de nombreuses courbes de marées de vive-eau) et des valeurs des courants mesurés au large. On a utilisé pour celà la relation théorique existant entre la pente superficielle de la mer dans une direction donnée, la dérivée par rapport au temps de la composante du courant selon cette direction et la composante perpendiculaire, pour une onde de marée "derivée." Les pentes calculées permettent le tracé des courbes de marée de proche en proche.

Les courants de marée dans cette région étant sensiblement alternatifs et, en un point, à peu près indépendants de la profondeur au moins jusqu'à une couche située à 5 mètres au-dessus du fond, les profils choisis entre la France et l'Angleterre sont à peu près normaux aux lignes de courant et présentent les avantages suivants:

— la formule de base est employée dans les conditions de précision maximum;

— la force de frottement exercée sur le fond a une composante très faible suivant le profil et a une influence probablement négligeable.

Les "courbes-types" de vive-eau moyenne qui servent de point de départ, tiennent compte des ondes M_2, S_2 et des ondes supérieures dont les situations sont déterminées quand celles de ces ondes le sont, c'est à dire M_4, S_4, MS_4, M_6, etc. . . .

Les mesures de courant utilissées ayant été faites en vive-eau et ramenées à la vive-eau moyenne par une loi linéaire suffisamment approchée constatée en divers points de la zone, on peut dire, qu'en moyenne la marée trouvée doit être la marée de vive-eau moyenne.

Des courbes types de Cherbourg, Barfleur, le Hâvre (double pleine-mer) on a déduit des courbes de marée pour Portland, Christchurch, les abords de Brighton et Beachy Head. Celles-ci font apparaître notamment:

— la double basse mer de Portland;

— la faible amplitude près de Christchurch (1 m. 8);

— une déformation des courbes près de Brighton et dans l'Ouest qui est une amorce de la double pleine-mer constatée a Portsmouth;

— une amplitude et des heures de pleine et basse mers sensiblement conformes à la réalité en tous les points de la côte anglaise où les heures, notamment, soient bien définies.

La "fermeture" sur la côte anglaise se faisant dans des conditions de précision acceptables, il semble possible d'admettre comme suffisamment approchées les courbes calculées pour le large. Celles-ci montrent que les déformations de la marée particulières à cette zone s'étendent au large et ne sont pas localisées aux côtes. On passe de façon continue de la courbe de Saint Vaast–la Hougue, qui presente un méplat après la pleine mer à la courbe obtenue partout sur le méridien de Beachy Head qui présente un méplat avant cette pleine-mer; les deux régimes sont probablement séparés par une courbe à méplat horizontal au voisinage de la pleine mer qui donne en particulier la double pleine mer du Havre.

La méthode employée fait ressortir notamment la sensibilité relativement très grande des mouvements horizontaux de l'eau à la pente souvent peu appréciable de la surface de la mer; elle pourrait, semble t-il, être employée avec fruit en vue de la réduction des sondes du large au zéro des cartes. Des observations de courant faites en vive-eau et en morte-eau en une série

de points alignés normalement à la côte (donc à peu près normalement aux lignes de courant) et des observations simultanées de la marée au rivage, permettraient d'établir dans des conditions de précision probablement assez grande une courbe de concordance entre la marée à la côte et la marée au large et de donner une base théorique plus solide à la réduction des sondes du large.

H 3

A New Method of Continuous Current-Measuring from an unattended Buoy

By

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To obtain reliable information on water movements in the sea, adequate in amount and representative enough of varying weather conditions, has usually necessitated the immobilisation of an expensive vessel. This has applied particularly to surveying vessels charged with the observation of tidal streams, but the interests of fisheries, scientists and others have been equally involved. Though recording current-meters have been successfully operated from "submarine stations," the problem of getting extensive data on water movements in the upper levels of the sea (applicable to the draught of a ship and therefore of direct navigational interest) has not yet been solved in so far as working from an unattended buoy is concerned.

The call has been for an instrument which could work unattended for long periods under adverse weather conditions and which could yield acceptable data in defiance of dirty and weedy water.

Proceeding from experience gained during long-maintained observations from light-vessels, an instrument considered capable of meeting the needs has been designed. A description of it will be given, and specimen records displayed should these have become available in time.

H 3.1

A New Repeating Current-Meter

By

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For the measurement of currents in the ocean many types of current-meters have been constructed. The Ekman current-meter is very handy for depths not exceeding some 50 metres. It has been widely used and is a very reliable instrument. Many types of electric registering current-meters have been invented, but the cable, which must necessarily be rather large and heavy, limits the use of such current-meters to the upper 100 metres.

For current measurements at greater depths, as far as I know, only two earlier current-meters meet the demand: the repeating current-meter of Ekman and the mechanical registering current-meter of Böhnecke. The current-meter of Böhnecke is excellent, but unfortunately extremely expensive. By means of a clock-work the direction of the vane and the number of revolutions of the propeller are printed on a strip of tinfoil. The current-meter may be left in the sea for many hours and the record is easily read off and may be kept for later examination. The Ekman repeating current-meter records the direction of the current and the number of revolutions of the propeller by means of numbered shots which drop into receptacles. The mechanism of recording is worked by means of messengers which can be sent down the sounding line and when hitting the lever they divide and fall into a bucket which is suspended below the current-meter. The use of this current-meter is somewhat complicated and the sorting of the marked shots is a rather tedious task.

The current-meter which will be described below combines,

in a certain manner, the recording principles of the Böhnecke and the Ekman current-meters. The number of revolutions of the propeller and the direction of the current are printed on a tinfoil strip as in the Böhnecke current-meter, but we have dispensed with the clock-work; the printing and the transport of the tinfoil are worked by means of messengers of the Ekman type. A propeller revolves in sapphire bearings and, by means of cog-wheels, drives two small counting wheels. The first of these makes one revolution for every hundred revolutions of the propeller. Its circumference is divided into ten parts with the numbers 0, 1, 2, 3, ... 9. The second wheel is divided in the same manner, but is only shifted one position for every turn of the first. In fact, it is a usual counting apparatus with the only difference that the numbers are engraved so that they may give an impression on the tinfoil strip when the tinfoil is pressed against it.

The compass-rose is deeply etched so that the numbers also give an impression on the tinfoil strip.

When the messenger hits the lever this will press a rod ending in a rubber plate against the tinfoil. In the tinfoil we then get an impression of the numbers and at the same time two fixed marks, one for the number of revolutions and one for the position of the vane. From the position of these two marks relatively to the division of the counting wheels and the compass-rose, the exact number of revolutions and the direction of the current can be read off to the nearest degree.

When the rod is lifted again by means of a spring the tinfoil is transported about 1 cm. further, to leave room for the next record. The number of records that can be obtained before the instrument is hauled on deck again is limited by the weight of the messengers. Some 50 messengers will probably be a suitable number; the messengers will then weigh about 9 kg. About 10 m. of tinfoil may be in store in the apparatus, and this will last for more than one day's measurements. The mechanical system is very simple so that little trouble should be experienced when using the apparatus.

H 5.2

Experiments on Bottom Friction

By

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The frictional influence from the bottom has been studied by means of a specially designed set of current meters. A 3 m. high stand, resting on the bottom, carried 12 cup wheels the revolutions of which were recorded by a photographic multicronograph on board the *Armauer Hansen*. In this way detailed variations of the current velocity were obtained simultaneously from 12 different levels, from 9 to 250 cm. above the bottom.

Good records were obtained from the tidal current in the narrow passage of Alværstrømmen, near Bergen, where the vessel could be very rigidly moored. The depth to the bottom was about 13 m. Although the current at this place is apparently not stationary and is certainly also depending on the local topography, the records show certain characteristics which are probably of more general interest.

Superposed on the mean tidal current velocity are a number of rapid variations with a predominating "period" of about 5 min., indicating a horizontal extension of the turbulence elements of about 12 metres. The "amplitudes" are reduced, and the variations also seem to be slightly retarded towards the bottom.

The vertical distribution of the velocities varies from minute to minute. The average distribution appears to be only roughly in agreement with the generally expected logarithmic law. The velocity at a distance of only 9 cm. from the bottom is strikingly high.

Further investigations will make necessary the construction of instruments also recording the direction of the current.

H 4

Spectrum of Gravity Waves in the Sea

By

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An attempt is made to examine systematically the mode of origin and the outstanding physical features of the spectrum of gravity waves in the sea for wave periods ranging from a fraction of a second to twenty-four hours. Particular emphasis is placed on the part of the spectrum corresponding to periods longer than the measured swell and shorter than the tides. Records obtained by an instrument especially adapted to this range of periods indicate a continual presence of waves in this unexplored portion of the spectrum of gravity waves in the sea.

H 4.1

Recent Studies of Waves and Swell

By

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The close examination of continuous wave records, made possible by newly developed wave-recording instruments, showed that full account must be taken of the fact that the recorded wave patterns are always combinations of a number of trains of waves of different length and velocity, the surface profile being the resultant of the combined vertical displacements. Attempts were made to study the component wave-trains by statistical analysis of crest-to-crest measurements, but it was soon decided that no fundamental advance could be made in the study of the generation and propagation of waves till a method was developed by which the complex wave record could be resolved into its individual waves in sufficient detail to allow the amplitude of each component wave train to be measured.

The examination of wave spectra obtained by submitting wave records to such frequency analysis shows that the mixture of waves generated in a storm comprises waves of all lengths up to a maximum which depends on the greatest wind strength. By comparing the measured times at which the different wavelengths begin and cease to arrive at a wave-recording station with the times (estimated from meteorological charts) at which they begin and cease to be generated in a distant storm area, it has been shown that the component wave-trains travel independently across the ocean at speeds within 5 per cent. of the theoretical group-velocities appropriate to their periods. The short waves generated at the beginning of the storm are overtaken and outdistanced by the longer waves generated when the wind is

stronger, and the separation between them increases with distance from the generating area.

The longest waves, which are the first to arrive at the recording station, may be as long as 3000 feet and only a few inches high, but they can be detected by making a frequency analysis of a sensitive wave record or by using an instrument designed to resonate with long-period waves. Shorter but higher swell follows the longest swell, and if the distance of the storm from the recording station is 1000 to 2000 miles a period of approximately 12 hours will usually elapse between the time at which the first low, long swell can be detected by sensitive instruments, and the time at which the shorter, higher swell becomes obvious to the eye among the waves caused by local winds. The trend towards shorter periods revealed by the analysis of successive wave records can be used to estimate the distance of the storm, though a precise answer can be expected only when the storm is of small extent and duration. If there are sufficient changes in intensity as the storm travels over a long ocean path, it may be possible to follow it by studying the trends of distinctive bands in the successive wave spectra, as if it were a succession of small storms.

A comparison between the recorded wave periods and the gradient wind speed in the strongest part of the storm shows that the maximum wave period is approximately one-third of the gradient wind speed, if the period is expressed in seconds and the wind speed in knots. The period of the highest swell in seconds is approximately a quarter of the gradient wind speed in knots.

The results obtained make it possible to use swell recordings made at a coastal station to study wave generation in a distant storm area, and if no meteorological information is available they could be used to estimate the strength of the wind in the distant storm area and the distance of the storm from the coast. The recording and analysing technique could also be used to obtain warning of the approach of heavy swell. The methods used and a theoretical basis to the work are described by Barber and Ursell in Phil. Trans. Roy. Soc., Vol. 240, p. 527.

H 5

Note on the Properties of Internal Waves

By

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The properties of internal waves have been studied by various authors from different points of view. In 1933 Fjeldstad devised a method of computing very long internal waves for arbitrary continuous vertical-density distributions by solving the pertinent differential equation by numerical integration.

It is possible to treat the problem analytically without introducing discontinuities of the density or of its vertical gradient by choosing certain special types of stable density distribution, for instance, the one described by

$$\rho = \rho_0 - \tfrac{1}{2}\Delta\rho \,.\, \tanh \alpha z,$$

where ρ is the density (as a function of the vertical co-ordinate z), varying smoothly from $\rho_0 + \tfrac{1}{2}\Delta\rho$ to $\rho_0 - \tfrac{1}{2}\Delta\rho$ in such a way that most of the transition is found within the layer between $z = -\alpha^{-1}$ and $z = \alpha^{-1}$. In this case we find, for any value of the wave-length L, an infinite set of corresponding values of the period T, corresponding to modes of oscillation of the fluid having increasing numbers of node levels.

A full account of this investigation is published in the series of the Koninklijk Nederlands Meteorologisch Instituut, Mededelingen en Verhandelingen Series B, no. 11.

The most interesting feature of the obtained result is that when $L \to 0$, $T \to T_{\min.} = 2\pi\sqrt{\left(-\rho/g\frac{d\rho}{dz}\right)_{\min.}}$, so that there is a lower bound of the periods, which is inversely proportional to the square root of the maximum value of the stability within the fluid.

It will be noticed that the above value of $T_{\min.}$ is equal to

the so-called period of free oscillation of particles belonging to the layer of greatest stability.

Although this result was first obtained from the solution corresponding to the special type of density distribution referred to above, it is possible to prove in a general way the existence of this lower bound of the periods of *internal* waves in any arbitrary vertical-density distribution, provided there is a layer of greatest stability beneath the surface. Since at a discontinuity of the density the stability is infinite, the lower bound for T vanishes in this case. In so far as the free surface of a fluid may be considered as a density discontinuity, even the surface waves fall within the scope of the above theorem.

H 6

Turbulent, Periodic and Mean Motions: Some Measurements in the Atlantic by B. Helland-Hansen and the Author

By

V. W. EKMAN
Sweden

The measurements were made in 1930 from the *Armauer Hansen*, anchored at six stations within the trade-wind region between Portugal and the Canaries in water between 1900 and 3970 m. deep. At each station measurements went on continually for several days (between 49 and 141 hours). Three current-meters were used simultaneously, so that complete measurements could be obtained at intervals of about 25 minutes at each of three different depths down to 50 m., and 2 or 3 hours at each of the depths 100, 300, 600 and 1000 m.

Our original design was to eliminate the disturbing effect of the ship's motions by taking mean values of repeated measurements, and thus to obtain representative values of the real direction and velocity of the current itself. Actually the ship's motions proved to be much smaller than expected, so that even single measurements might so far be representative of the real conditions in the sea. A more serious difficulty about the accurate determination of the average current was, however, the various transient motions in the water itself, the satisfactory elimination of which might have demanded still longer periods of observation than conditions in our case allowed.

On the other hand, interesting information concerning the structure of the currents was obtained. Diurnal and semi-diurnal periodic oscillations were generally obvious at all

levels, and they often constituted the chief part of the motion, reaching exceptional velocities of 10 cm./sec. and more. They had generally the character of elliptic motions described in the *cum sole* direction. Originally we took for granted that they were tidal motions, and therefore confined ourselves by harmonic analysis to calculate *lunar* diurnal and semidiurnal oscillations. A closer examination of our longest series of measurements (141 hours) indicated, however, that the diurnal period was not 24 *lunar* but more likely 24 *solar* hours or perhaps even slightly shorter. Since the station in question lay on nearly 30° latitude, the day (or more exactly $23^h\ 47^m$) was equal to 12 pendulum hours. The oscillations might therefore be interpreted as *free inertial oscillations*; at any rate in the uppermost layers, where the motion was almost exactly circular and with the same amplitude and phase-constant at all levels down to 35 m. From 100 m. and downwards the orbits were more or less oval and with varying orientation, but everywhere described *cum sole*.

In some places other oscillations were found at single levels, *e.g.* with periods of about 18 or 19 hours at 5 and 300 m., 29 or 30 hours at 100 and 300 m., and 36 hours at 600 m. It has not been possible to find any reasonable explanation of these puzzling periods, but it seems difficult to deny their reality. The motions all follow elliptic orbits, which are described *cum sole*.

After subtraction of the velocity components due to all these periodic motions, the remainder was examined by formation of progressive averages over 9 and 12 or over 15 and 24 hours. In this way "variable mean values" were obtained, to which we will return shortly. After subtraction of them as well, the remainder was characterized by diagrams with comparatively rapid fluctuations to both sides of the time axis. (Order of magnitude of the duration of individual fluctuations a couple of hours, say.) These fluctuations are naturally interpreted as a manifestation of turbulence. Their characteristic features never appear simultaneously at all levels, and they cannot, therefore, be explained as an effect of the ship's motions only. They often reappear, however, at two or three adjacent levels. One day, for instance, there was an obvious resemblance between the diagrams for 100 and 200 m., and traces of their characteristic

features could be recognized in the curves for 50 and 300 m. Possibly this may be an indication of the occurrence of "turbulence bodies" (within which the water has in some degree a common motion, approximately as one body) with a vertical extent of a couple of hundred metres and with horizontal dimensions which are, therefore, likely to have been of at least the same size. These turbulence bodies have made excursions with an order of magnitude of 100 or 1000 m. in horizontal directions. The influence of the earth's rotation on their motion could be verified at some stations, the phase difference between their meridional and zonal components indicating in the majority of cases a curvilinear motion *cum sole*.

The turbulent motions thus examined had "periods" or average durations lying between an hour and a few hours. This limitation is, however, simply a consequence of the method of investigation. A more extensive "spectrum of turbulence," including longer as well as shorter "waves," would *a priori* be expected. As a matter of fact the gradual alterations of velocity appearing in the above-mentioned "variable mean values" might to some extent be interpreted as a super long-wave turbulence, as far as they are not due to alterations of wind, for example. On the other hand, an ultra short-wave turbulence is supposed to be the cause—or a contributive cause—of the spread of the direction records combined with each separate record of velocity. On this supposition some conclusions were drawn on the average velocities of the corresponding turbulent motions.

At one station we happened to witness two great, accidental outbreaks of current, which for some hours entirely altered the motion of certain water-layers.

With regard to the average motion, it deserves mentioning that the water north of Madeira was found to run *eastwards* at all levels and the water off the Portuguese coast *northwards*, thus in agreement with the views first expressed by NANSEN and afterwards supported by dynamical calculation.

H 7

The Theory of Mixing of Sea-Water through Turbulence

By

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The theory of diffusion by continuous movements, due to Sir G. I. Taylor, is applied to the variation, both in space and time, of the distributions of temperature and salinity in the sea.

It is assumed that the correlation between certain quantities depending on the turbulence at one instant and other quantities depending on the turbulence at a subsequent instant are zero if these instants are separated by more than a certain minimum interval of time τ.

The turbulent displacements of a particle of water from time zero to time t are denoted by ξ, η, ζ. A mean value through a fundamental volume centred on the point x, y, z at time t is denoted by the symbol [ ], and the mean salinity, in this sense, at time t and at a point x, y, z is denoted by $S(t, x, y, z)$.

It is shown that, for $t > \tau$,

$$S(t, x, y, z) = [S(0, x-\xi, y-\eta, z-\zeta)],$$

and that the time rate of passage of mass of salt across a small area perpendicular to Ox, due to turbulence, is

$$\frac{\rho}{1000}\left[S(0, x-\xi, y-\eta, z-\zeta)\frac{\partial \xi}{\partial t}\right]$$

per area, where ρ denotes the density of sea-water.

If K_x denotes the coefficient of eddy diffusion in the x-direction, as usually defined, then

$$\left[S(0, x-\xi, y-\eta, z-\zeta)\frac{\partial \xi}{\partial t}\right] = -K_x \frac{\partial}{\partial x} S(t, x, y, z).$$

It follows that, in general, K_x does not depend only on the state of turbulence, but depends also on the distribution of temperature or salinity. In general, the coefficient of eddy diffusion, as determined from the distribution of temperature, will be different from that determined from the distribution of salinity, in the same region of the sea at the same time. The two coefficients will be equal only in certain simple cases. Such a simple case is provided by the central region of the Irish Sea, and the theory is applied to estimate that the mean current through this region is 2·5 cm./sec.

(The complete communication has been published in Proc. Roy. Soc. A, vol. 195, pp. 300–309, 1948.)

H 8

A New Accurate Burette for Small Volumes

By

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With the intention of attaining special advantages in titration of sea-water the author has, during the War, constructed a burette, whose two essential parts are an automatic syringe-pipette (A. Krogh; "Syringe Pipets," Ind. Eng. Chem., Anal. Ed., vol. 7, p. 130, 1935) and a precision micrometer screw. The burette in question measures liquids of a volume up to 10 cm.^{3} with a mean error of the order of magnitude of $\frac{1}{2}$ mm.^{3}, which error is twenty to thirty times smaller than the error found in cases of ordinary burettes.

In Denmark two burettes of the reported kind have been made. Up to now a description of the construction and use of the burette has been published only in Danish (Kemisk Maanedsblad, 1943, Nr. 8).

The burette has provisionally been used for the determination of salinity in about 1000 samples of sea-water. Two modifications of the special titration method have been elaborated, the one based on Mohr's, the other on Volhard's chemical manner of proceeding.

The two above-mentioned modifications allow the same degree of accuracy (same absolute value for the mean error) as the Knudsen method (M. Oxner: "Manuel pratique de l'analyse de l'eau de mer. 1. Chloruration par la méthode de Knudsen," Bull. Comm. Méditerranée, No. 3) for all concentrations. It should, however, be added that the accuracy of the Volhard modification for small volumes is higher than that of the Knudsen method.

Below is given some essential features of the elaborated modifications of titration.

1. For titration of a sample of sea-water the Mohr modification requires 8 cm.^{3} and the Volhard modification 3 cm.^{3} of the sample, including the water used for rinsing the pipettes.

2. The expense of silver nitrate, which is at times very difficult to provide in large quantities, is in the Mohr and Volhard modifications quite trifling, the quantities used amounting to respectively $\frac{1}{7}$ and $\frac{1}{20}$ of the quantities used in the Knudsen method.

3. Each titration takes practically the same time to perform as by the Knudsen method, the Mohr modification requiring 5 minutes, the Volhard modification 6 minutes, on an average, everything included.

4. No cocks are found in the apparatus for the two modifications; consequently no grease for glass stopcocks is needed, and thereby also the attendant disadvantages are avoided.

5. No cleansing with chromic sulphuric acid or with similar cleaning liquids should be made. The only cleansing required is the rinsing of the burette at certain intervals.

6. The two modifications—preferably, however the Mohr modification—can be used on board hydrographic vessels, even in rough weather.

It should be added that the accuracy obtained by the Volhard modification may be further increased by a dilution of the samples of sea-water and by other measures. The burette, of course, can be used for other purposes than that of titration of sea-water.

H 8.1

Bathythermograph Sea Sampler

By

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The new bathythermograph sea sampler comprises twelve sample bottles which attach to a standard bathythermograph. The bottles are arranged to trip at various pressures, which can be selected at will.

The whole instrument is compact, so that it will not present great resistance when passing through the water. The tripping mechanism closes the bottles in succession as the instrument comes up from the lowest depth reached. Should samples not be desired, the bottles and triggers may be instantly removed, without the use of any tools, and the instrument is then identical to an ordinary bathythermograph and may be used as such.

The sampler has been employed successfully from a vessel under way at over 10 knots and should be able to be utilized at just as high speeds as the simple bathythermograph.

The effect of imperfect exchange of water through the sample bottles has been studied theoretically and by tests. The error in a constant gradient of concentration may be expressed as a depth which is given by a "characteristic length" of the sampler bottle and the angle of inclination of its path through the water. The error can be shown to be the projection of the "characteristic length" on the vertical. The "characteristic length" of the present sampler is 2·5 m. and this therefore is its maximum error (when used hove-to). At 10 knots the error is less than 0·3 m.

Several sections have been made off Georges Banks and

both oxygen and salinity determined for all soundings. In these sections, while travelling at $10\frac{1}{2}$ knots, it was possible to obtain a sounding (temperature record and 12 water samples) every twenty minutes. The sampler has also been used successfully for determining the distribution of concentration of ferrous iron behind a barge depositing waste acid in a harbour.

H 9

Storm Surges in the North Sea

By

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The problem of storm surges is much more intricate than is usually supposed, particularly in the case of a semi-enclosed sea like the North Sea, since there are three contributions to be considered: the effects of winds in the vicinity of the place of observation, the effects of winds over the major part of the sea, and the effects of travelling surges propagated inwards into the sea. These effects have to be disentangled; each has its own dynamical characteristics; and none exists apart from the others. The problem has been solved for the Thames estuary, and remarkable quantitative results have been obtained for every one of a large number of cases. The daily forecasting of these effects is now a possibility.

The interaction of these surges with the tides gives rise to apparent oscillations of much shorter periods than those of the main oscillation. They may be "shallow-water tides," and as they tend to give peaks to the main surges these peaks may actually be the most dangerous parts of the surge. This problem has not been solved.

The characteristics of the surge may be used in the study of the dynamics of the movement; in particular, values of damping constants are of interest in the estimation of internal friction and possibly of bottom friction.

H 9.1

Deep Scattering Layers in the Pacific and Antarctic Oceans

By

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Underwater sound investigations during the war revealed the common presence of deep layers in the ocean which scatter sound. These deep scattering layers are formed by scatterers that descend in the morning from near the surface and ascend in the evening, indicating that this phenomenon is produced by vertically migrating organisms that probably move in response to a negative geotropism which is dominated by a negative phototropism.

Examination of continuous fathograms across the Pacific and into the Arctic and Antarctic Oceans revealed an almost continuous distribution of deep scattering layers at depths from 150 to 450 fathoms during daylight. Rarely the phenomenon is developed at night. Double descending layers of scatterers were occasionally observed in the morning and as many as three simultaneously developed layers are common, showing that many types and/or developmental stages of organisms are involved. Although sporadically present, the deep scattering layers were not generally detected during the period of permanent or almost permanent daylight of the Antarctic midsummer.

It is not at present known whether the scatterers are zooplankton or larger forms such as fish or squid; however, the evidence thus far, such as the extensive and continuous distribution, the method of migration, and some net haul data, is more suggestive of zooplankton.

H 9.2

SOFAR: A New Oceanographic Research Tool

By

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SOFAR (*SO*und *F*ixing *A*nd *R*anging) is a system utilizing the deep sound-channel in the ocean for the transmission of sound over distances of hundreds to thousands of miles. The feasibility of the system was demonstrated in a series of Atlantic tests in 1945, conducted for the Bureau of Ships, Navy Department, by the Woods Hole Oceanographic Institution in co-operation with the U.S. Navy Underwater Sound Laboratory. The first regular SOFAR network is being installed in the Pacific by the U.S. Navy Electronics Laboratory, in co-operation with other agencies, and will be completed during 1948.

Though designed primarily for the location and rescue of survivors at sea, SOFAR offers a new approach to the solution of several oceanographic problems. For example, subsurface currents can be measured by determining the drift of buoys submerged at the desired depth and releasing signal bombs periodically. Accurate determination of sound travel-time over a known path will furnish a measure of the mean temperature of the surface layers of the ocean, providing new data on heat exchange between the ocean and the atmosphere. Sea mounts and other submerged topographic highs may be located in some cases by the acoustic shadows cast by them. Also, the occurrence and possibly the location of submarine volcanic eruptions may be indicated by the sounds emitted.

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